

Project AIR FORCE

# THE NEXT- GENERATION ATTACK FIGHTER

## AFFORDABILITY AND MISSION NEEDS

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Donald Stevens, Bruce Davis, William Stanley  
Daniel Norton, Rae Starr, Daniel Raymer  
John Gibson, Jeffrey Hagen, Gary Liberson

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## PREFACE

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This report examines key affordability and mission needs issues for the Joint Strike Fighter (JSF). This fighter is the subject of the ongoing Department of Defense Joint Advanced Strike Technology (JAST) program. Complementing the F-22, it could become the most numerous fighter in the Air Force inventory. The analysis here is tailored to support the Air Force in developing the JAST Mission Needs Statement (MNS) and the Operational Requirements Document (ORD), and in evaluating contractor studies.

This work was done in the Aero-Systems Modernization Project, part of the Force Modernization and Employment Program of RAND's Project AIR FORCE. It was sponsored by the DCS/Plans and Operations, Headquarters, USAF, and DCS/Requirements, Headquarters, Air Combat Command. The work should be of interest to personnel who address fighter requirements, force structure, and acquisition issues.

Project AIR FORCE, a division of RAND, is the Air Force federally funded research and development center (FFRDC) for studies and analyses. It provides the Air Force with independent analysis of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is being performed in three programs: Strategy and Doctrine, Force Modernization and Employment, and Resource Management and System Acquisition.

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## SUMMARY

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The Air Force has embarked on a course to replace the most numerous fighter aircraft in its inventory, the F-16. The Joint Strike Fighter (JSF) may evolve from the tri-service Joint Advanced Strike Technology (JAST) program to replace the F-16 (and perhaps other Air Force ground-attack aircraft) as well as other air-to-ground fighters used by the Navy and Marine Corps. As the JAST program proceeds to a hardware demonstration phase, the Air Force is drafting statements of mission needs and operational requirements for the new aircraft.

The Air Force asked RAND's Project AIR FORCE to analyze inventory levels, affordability, and mission needs for the new fighter, to augment Air Force and contractor studies. The study, documented in this report, found that the constraints of future budgets will severely circumscribe Air Force options for the JSF. Without a sharp reversal in defense budget trends or the allocation of a higher share of the Air Force budget to fighter modernization, the JSF will need to be a relatively low-cost, moderate-performance aircraft to fit within Air Force budget constraints. The good news is that an aircraft with a combat radius of 650 nm, moderate stealth, and a turn rate comparable to that of today's multirole aircraft can probably meet most of the services' needs in future regional conflicts.

### WHEN AND HOW MANY?

The Air Force will need large numbers of JSFs—on the order of 1600 to 2600 airplanes, depending on the specific airplanes the JSF replaces, in the fighter force structure. Similarly, the Air Force will need to procure JSFs at high rates—probably in excess of 120 aircraft

per year—as F-16s are retired in large numbers because of age. Accommodating the budgetary impact of such procurement rates within the constrained Air Force budgets of the future represents a major challenge.

Methods for adjusting the required introduction date of the JSF include retaining Cold War-era aircraft longer than currently planned or buying more F-15Es and/or F-16C/Ds. Accepting force structure reductions below 20 fighter wings—perhaps with compensatory actions, such as improved weaponry to mitigate capability impacts—is a third method. Such options must be assessed for their effects on force capability and on the industrial base for combat aircraft.

## AFFORDABILITY

What the Air Force can afford to pay for a JSF depends on the budget it can allocate to fighter modernization, the mix of F-22s and JSFs it buys, the cost of the F-22, and the size of the fighter force structure. The interplay of these factors is shown in Figure S.1.

The three graphics in the figure assume different budget shares for fighter procurement, given a future Department of Defense (DoD) budget estimate of \$227 billion. Even an average share of this budget for fighter procurement—shown in the middle graphic as \$4 billion annually—is not assured, given the pressure future DoD budgets will be under, the competition fighter-modernization accounts will face from other accounts, and the fact that operation-and-maintenance and personnel accounts are currently taking more than their historical shares of the budget.

The figure illustrates how the cost of the JSF the Air Force can afford varies with the size of the fighter force structure (16 to 20 wings) and the number of F-22 wings procured (2 to 6). For this example, an F-22 flyaway cost of \$71 million is assumed, which does not include cost growth beyond current cost estimates as the aircraft goes through its full production life. The graphic in the middle of the figure, for example, shows that if the Air Force has a \$4 billion fighter-procurement budget and holds to its objective of 20 fighter wings with 4 wings of F-22s, it could afford a JSF costing slightly less than \$26 million. This is roughly the cost of a F-16C with night-attack equipment today. Affording a \$30- to \$40-million JSF—a plausible

cost range for a new airplane—could require either an increase in the fighter-procurement budget or some combination of force structure cuts and changes in the mix of F-22s and JSFs.

Figure S.1 underscores the importance of not overstating JSF requirements. Again examining the middle graphic on Figure S.1, if the cost of the JSF were to grow from \$26 million to \$35 to \$45 million to meet more demanding requirements, it could have a serious effect on the fighter force structure. That imperative shaped our assessment of the key mission needs the JSF would have to satisfy: We looked for ways to use weapon capabilities and support from other assets to moderate the stringency of design requirements for the JSF platform.

Finally, there has been considerable discussion of a balanced federal budget. If the federal budget were balanced during the time the JSF is procured, and most of the spending cuts were made in discretionary accounts (as opposed to entitlements), then \$3 billion per year is a more likely budget for Air Force fighter modernization.

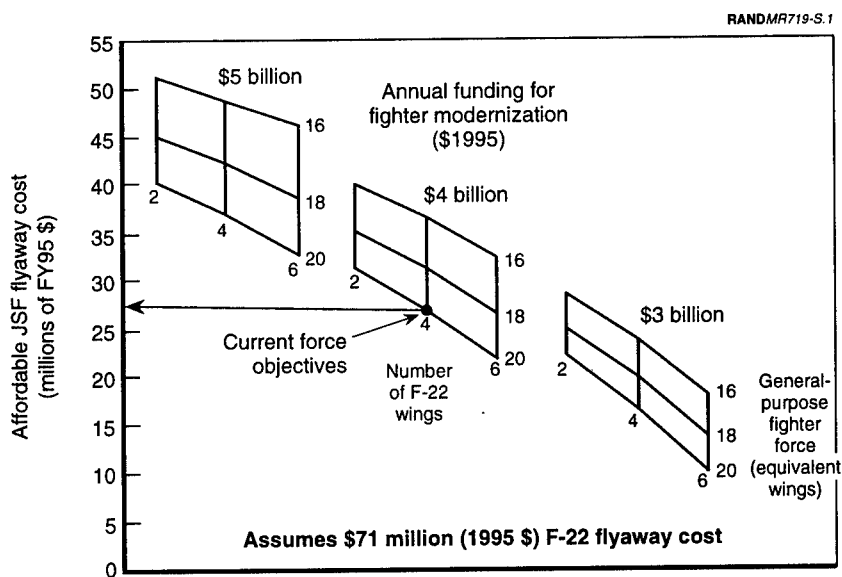


Figure S.1—Budget, Force Size, and Force Mix Influence JSF Cost

Given these circumstances, a 20-fighter-wing force structure with 4 wings of F-22s and 16 wings of JSFs appears unaffordable.

## DESIGN CHARACTERISTICS

We examined mission needs in several key areas that strongly influence aircraft cost, including

- combat radius
- stealth
- maneuverability
- compromises for design commonality.

### Combat Radius Needs

The combat-radius requirement for a fighter aircraft exerts a strong influence on the size, and therefore the cost, of a new aircraft. This analysis calculated the radius requirements for

- three theaters
  - Iran
  - Iraq
  - North Korea
- three basing options
  - optimistic (close to the theater)
  - fallback (in the rear to avoid attacks by tactical ballistic missiles or enemy ground forces)
  - offshore (flying from Japan for operations in North Korea or from carriers for operations against Iraq or Iran)
- three in-flight refueling options
  - two-way (refueling on both ingress and egress)
  - one-way (refueling on egress only)
  - none

- three levels of support from other assets in the theater
  - no support
  - three days of heavy bomber sorties and cruise missiles from one carrier battle group
  - seven days of bomber sorties and cruise missiles from three carrier battle groups.

With favorable basing, an aircraft having a 650-nm combat radius can hold at least 70 percent of the targets at risk in any of the three theaters without refueling. The same percentage of targets can be held at risk with a 650-nm radius and less-favorable basing if some in-flight refueling support is available. Aircraft radius would have to increase to 800 nm or more to reduce the dependence on in-flight refueling significantly. In contrast, decreasing the aircraft radius from 650 nm to 600 nm would increase dependence on in-flight refueling significantly. With support from sea-based attack assets and bombers and with some in-flight refueling, a 650-nm radius is probably sufficient for a JSF.

### **Stealth and Standoff Weapon Trade-Offs**

Stealth is a major reason that the Air Force and the Navy want a new aircraft rather than a derivative of an existing aircraft. It is difficult to modify an existing design to achieve the same level of stealth as a new design. The stringency of stealth requirements will probably determine whether derivatives of the F-15E, F-16C, and F-18E/F can compete to satisfy the JSF need.

This analysis assessed how various degrees of radio frequency (RF) stealth—combined with weapons having various standoff ranges—influence an aircraft's ability to attack targets with impunity from medium altitude in three theaters (Iran, Iraq, and North Korea) and with four different levels of support from other assets in the theater. Results show that moderate stealth, coupled with some degree of standoff and advanced countermeasures, is probably sufficient for survivability in regional threat environments. Derivatives of existing designs equipped with appropriate weapons may be viable and should not be excluded from consideration because of survivability concerns.

## **Maneuverability and Armament Trade-Offs**

Turn-rate requirements exert a strong influence on the overall aerodynamic performance requirements of fighter aircraft. This analysis found that, while high aircraft turn rates contributed to improved survivability when aircraft faced older surface-to-air and beyond-visual-range air-to-air missiles, high aircraft turn rates had little effect against newer ones. Furthermore, we found that high-performance, short-range, air-to-air missiles with helmet-mounted sights are more important to the outcome of close-in air-to-air combat than high aircraft turn rates.

Our analysis suggests that the capability offered by high-performance, short-range, air-to-air missiles (AIM-9X or ASRAAM) and associated targeting aids may permit some relaxation of aircraft turn-rate requirements in the interests of affordability while still retaining a level of superiority in close-in combat comparable to that which the Air Force has historically enjoyed.

## **Compromises Associated with Design Commonality**

If the JSF is a new aircraft design, it is likely that it will be derived from a platform common to the three services to achieve economies of scale in production. Each service will tailor the platform to meet its particular needs, paying some weight and performance penalties in comparison with an aircraft designed to meet the needs of a single service exclusively.

This analysis assessed the range and gross-weight penalties the Air Force could incur from buying a derivative of a short takeoff and vertical landing (STOVL) or of a conventional takeoff and landing (CTOL) aircraft suitable for operations from aircraft carriers (see Figure S.2).

Compared to a land-based design, an Air Force derivative of a carrier-suitable CTOL design paid a 15-percent range penalty (6.1-percent gross-weight penalty). The range penalty for an Air Force derivative of an STOVL design was less—9 percent (3.8-percent gross-weight penalty). Using the STOVL rather than the CTOL as a basis for the JSF has two other advantages: The STOVL design would provide additional fuel capacity in place of the engine (or fan) and

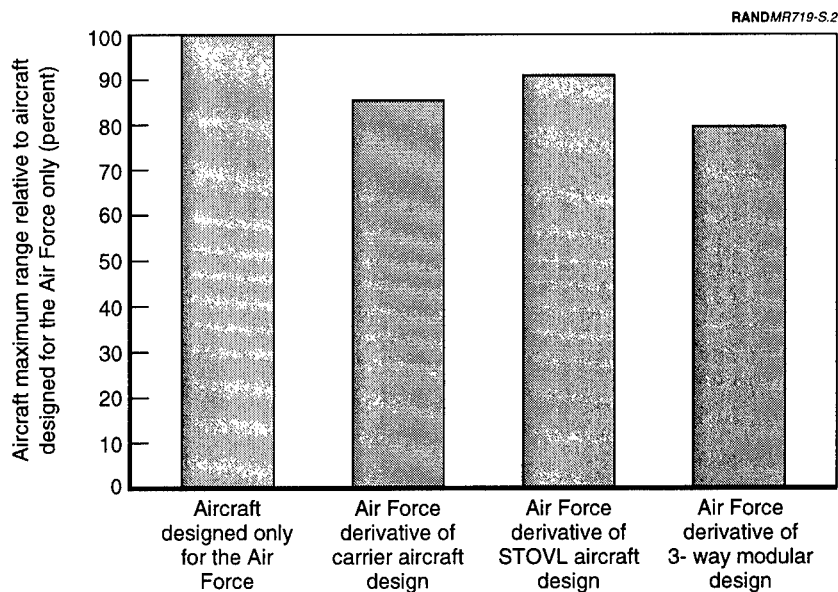


Figure S.2—Impact of Commonality on Range

would not impose the structural-weight penalty of an aircraft designed for catapult launches and arrested landings.

This research also examined a three-way modular design that would allow each service to develop its own aircraft from a common baseline. Assuming normal design practice, the analysis found that the Air Force version would suffer a 20-percent range penalty, as shown in the last bar of Figure S.2. However, the as-yet-unproven “cousins” approach, in which similarly shaped parts are built with different thickness for different aircraft, may recover some of the weight and range penalty.

## CONCLUSION

The new environment, featuring regional threats rather than a superpower competition, may provide some relief from the stringent requirements that drove up costs during the Cold War. A total force perspective will also be essential for setting affordable design param-



eters: Other assets, such as standoff weapons, advanced air-to-air missiles, and heavy bombers, can complement the JSF to permit some relaxation of its design requirements.

Nevertheless, the Joint Strike Fighter will be the most versatile multi-role fighter ever built, and making it affordable will be a serious challenge. Affordability will have to be one of the main ingredients in the design trade-off process. The Air Force will also have to devote an increased share of its budget to fighter acquisition to meet current force structure and force mix goals. Even with rigorous cost controls, challenges lie ahead in introducing a JSF without creating an unaffordable budget bow wave as the Air Force acquires several major new systems at the same time after the turn of the century.

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## ACRONYMS

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AAA	Anti-Aircraft Artillery
AD	Air Defense
AMRAAM	Advanced Medium Range Air-to-Air Missile
ASRAAM	Advanced Short Range Air-to-Air Missile
BAI	Battlefield Air Interdiction
CBU	Cluster Bomb Unit
CC	Combat Coded
C&C	Command and Control
CONUS	Continental United States
CTOL	Conventional takeoff and landing
CV	U.S. Navy Aircraft carrier designation
DoD	Department of Defense
ELINT	Electronic intelligence
FAC	Forward Air Control
FEBA	Forward Edge of Battle Area
FMS	Foreign Military Sales
FWE	Fighter Wing Equivalent
GCI	Ground Control Intercept
GDP	Gross Domestic Product
HMS	Helmet-Mounted Sight
IADS	Integrated Air Defense System
JAST	Joint Advanced Strike Technology
JDAM	Joint Direct Attack Munition

JSF	Joint Strike Fighter
JSOW	Joint Standoff Weapon
LGB	Laser Guided Bomb
LSF	Low Stealth Fighter
MNS	Mission Needs Statement
MSF	Moderate Stealth Fighter
ORD	Operational Requirements Document
R&D	Research and Development
RCM	Regional Conflict Model
RCS	Radar Cross Section
RDT&E	Research, Development, Test, and Evaluation
RF	Radio Frequency
SAM	Surface-to-Air Missile
SEAD	Suppression of Enemy Air Defenses
SFW	Sensor Fuzed Weapon
SLEP	Service Life Extension Program
STOVL	Short Takeoff and Vertical Landing
TBM	Theater ballistic missile
TF	Training aircraft designation
TLAM	Tomahawk Land Attack Missile
TOA	Total Obligational Authority
USMC	United States Marine Corps
V/STOL	Vertical/Short Takeoff and Landing
WMD	Weapons of Mass Destruction

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## WHEN AND HOW MANY?

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In this chapter we examine how many JSFs the Air Force needs to replace the F-16C/Ds to meet its force structure goals, and when those aircraft need to be introduced.

### TOTAL INVENTORY REQUIREMENTS

We can derive insights about when new aircraft are needed by comparing the inventory requirements for a general purpose fighter force of 20 fighter wing equivalents (FWE), supplemented by approximately three wings of Continental United States Air Defense (CONUS AD) and Forward Air Control (FAC) aircraft, to a profile of the Air Force's projected fighter/attack aircraft inventory. The assumptions used in the analysis conform to current Air Force plans, with two exceptions. First, we assumed the Joint Strike Fighter (JSF) will ultimately replace the approximately three equivalent wings of CONUS AD and FAC aircraft. To date, the Air Force has not announced a plan for replacing these aircraft. Since the JSF will likely be the least expensive aircraft in the Air Force fighter inventory, we assumed it would ultimately be used to fulfill those mission roles. The second exception involves the F-22. The Air Force currently plans to buy four wings (442 aircraft) of F-22s. We assumed the last two of these wings will have enhanced air-to-ground capabilities to replace the F-15Es and F-117s in the current force structure. We are driven to this assumption because considerable evidence suggests that the Air Force cannot afford to buy four wings of F-22s for the air-to-air role and an additional two wings dedicated as interdiction aircraft while also procuring a JSF at a cost consistent with that of

current- or next-generation aircraft. In addition, we did not want to impose the first-day survivability requirements of the F-117 and the deep-attack requirements of the F-15E upon a new JSF aircraft that will need to replace well over half of the Air Force’s fighter force.

Figure 1.1 shows the aircraft procurement required for a force structure of 20 fighter wings. The procurement calculations include aircraft required for basic operations, training, testing, and depot maintenance and modification, and an attrition reserve for 29 years of operations. The 29-year-life estimate assumes an 8000-hour aircraft operated at 275 hours per year. The peacetime attrition is based on historical experience. The Air Force would need to procure over 2600 aircraft,<sup>1</sup> over 29 years, to maintain 20 manned fighter wings. If JSF were not used to replace some of these aircraft types, the requirement could be lowered proportionally.

HOW REQUIREMENTS COULD VARY

We will examine how the requirements could vary with changes in force structure, service life assumptions, aircraft procurement plans, and aircraft retention plans.

Figure 1.2 illustrates the aggregate fighter inventory replacement challenge facing the Air Force. For the most part, future retirements

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16 fighter wings for general purpose forces (100 ac/wing)	=	1600 aircraft
~ 3 fighter wings for CONUS AD and FAC (100 ac/wing)	=	300 aircraft
Attrition reserve (1.3 losses/wing/year for 29 years)	=	716 aircraft
Total		= 2616 aircraft

Figure 1.1—Aircraft Procurement Calculations

<sup>1</sup>Not all of these aircraft will necessarily be JSFs. Thirty years from now, some of the missions now envisioned for the JSF may be flown by unmanned air vehicles or other assets.

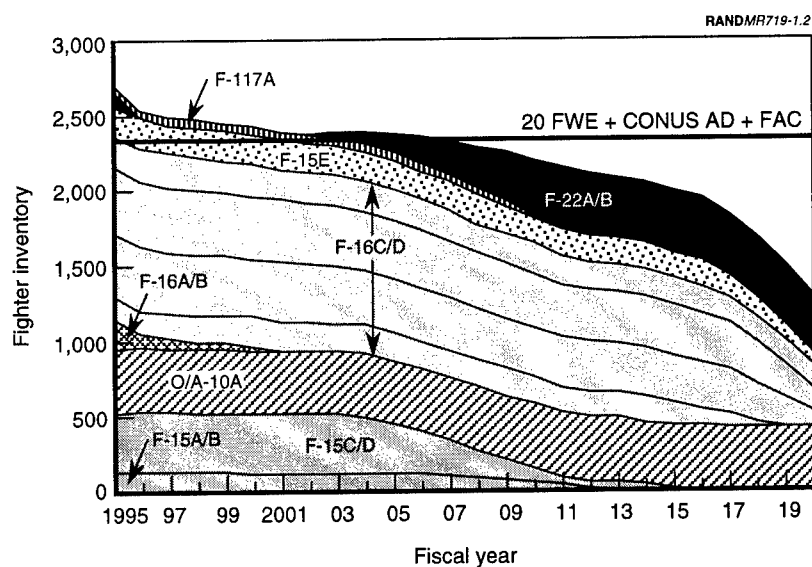


Figure 1.2—Air Force Fighter Inventory

are assumed to be driven by service life limitations.<sup>2</sup> The horizontal lines define the number of aircraft required to support the 20-fighter-wing force structure with approximately three wings of CONUS AD and FAC aircraft exclusive of attrition reserve aircraft.<sup>3</sup>

The top line on Figure 1.2 shows how the aggregate fighter inventory declines over time through attrition and retirements. The attrition reserve for the overall force is not exhausted until about 2005, when the top line of the inventory curve falls below the horizontal line.<sup>4</sup> However, since all aircraft are not interchangeable across all missions, the total picture masks shortfalls in the inventories of specific

<sup>2</sup>These estimates were developed using data from aircraft program offices and USAF/XOFC.

<sup>3</sup>A fighter wing equivalent consists of 72 combat-coded (CC) aircraft, 18 aircraft for training (TF), 2 aircraft for testing, and 8 for depot maintenance and modifications. The F-16 requirement also includes 40 aircraft used for training in support of Foreign Military Sales (FMS). These aircraft are in units that are manned, trained, and equipped by the U.S. Air Force, but are not part of the fighter force structure.

<sup>4</sup>This assumes that the F-22 is acquired at a rate of 48 aircraft per year.

aircraft types. In particular, the F-16 force exhausts its attrition reserve well before 2005, as shown in Figure 1.3.

### F-16 INVENTORY MANAGEMENT CHALLENGES

The Air Force faces two challenges in managing the F-16 inventory: In the short term, inventories fall below required levels due to peacetime attrition, and in the long term the aircraft will have to be replaced at high rates as they reach the end of their service and are retired.

#### Peacetime Attrition

The shallow slope of the top curve of Figure 1.3 reflects normal peacetime attrition of the F-16. If the Air Force continues to lose 15 to 17 F-16s per year through attrition, it will not have enough aircraft

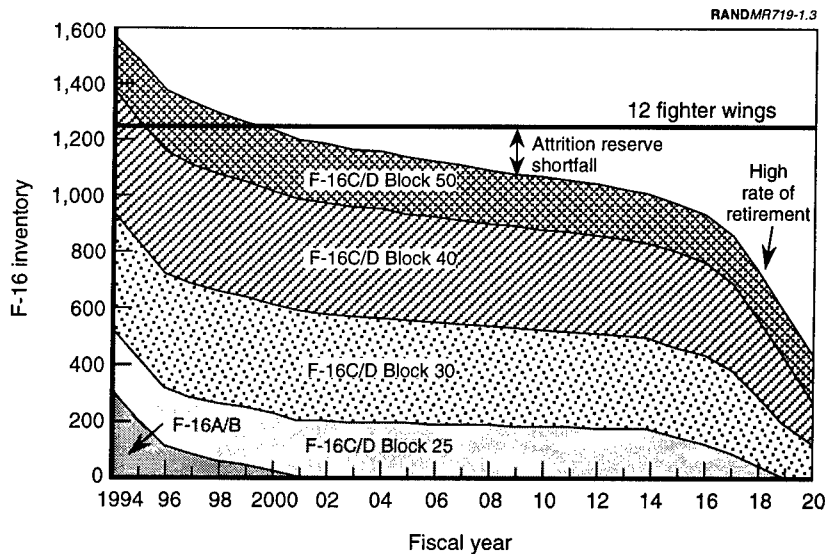


Figure 1.3—F-16 Fighter Inventory



to fill 12 fighter wings in the early part of the next decade.<sup>5</sup> A new aircraft, such as the JSF, cannot be developed and procured in time to solve this short-term problem. Delays in the JSF could exacerbate the problem, as we will illustrate later.

There are a number of possible solutions to the attrition reserve problem. First, the Air Force could decide not to retire the F-15A/Bs before the end of their service life, as they currently plan to do at the introduction of the F-22. If the Air Force were to move some of these F-15s into CONUS air defense and shift the F-16s in CONUS air defense into the general-purpose fighter force, it would free up other aircraft to be used as attrition reserves, delaying the inventory short-fall for a few years. Second, the Air Force could extend the life of the F-16A/Bs through a service life extension program (SLEP). SLEPing the 180 F-16A/Bs to 8000 hours would resolve the attrition reserve problem but could cost \$2 billion (\$ 1995). Although SLEPing F-16s would seem to be an obvious solution to the Air Force's short-term modernization problems, it is not clear that spending \$10 million on each F-16A/B for an additional 4000 hours is a wise investment. Third, the Air Force could procure an additional 144 current-generation aircraft such as the F-16C/D and F-15E. This solution could cost between \$3 and \$4 billion depending on the mix of F-16C/Ds and F-15Es procured. While this option is more expensive than extending the life of F-16C/Ds, it would provide a much more capable force.

### High Retirement Rate

The second challenge in managing the F-16C inventory is the high retirement rate, which may start in 2015 when the F-16C inventory is projected to reach its service life limits of 8000 fatigue life hours. Many of these aircraft were bought during the Cold War at a rate of 180 aircraft per year, and may have to be retired at similar rates. Even worse, older and newer model F-16s are projected to reach retirement at similar points because newer-block aircraft are used more intensively than older ones. In an austere funding environment, the rate at which F-16s leave the force because of service life

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<sup>5</sup>Additional procurement of F-15Es and F-16C/Ds could change this picture significantly.

retirements may exceed the Air Force's ability to replace them with JSF aircraft. This problem could become even more severe if the aircraft do not meet their assumed service life of 8000 fatigue life hours. If they are found to reach the end of their service life at 6500 hours, for instance, they will have to be retired approximately six years earlier. Another option, which we will touch on later, is flying the F-16Cs fewer hours per year. While this could delay the need to replace the F-16Cs and save money, it would adversely affect training and readiness.

## CONCLUSION

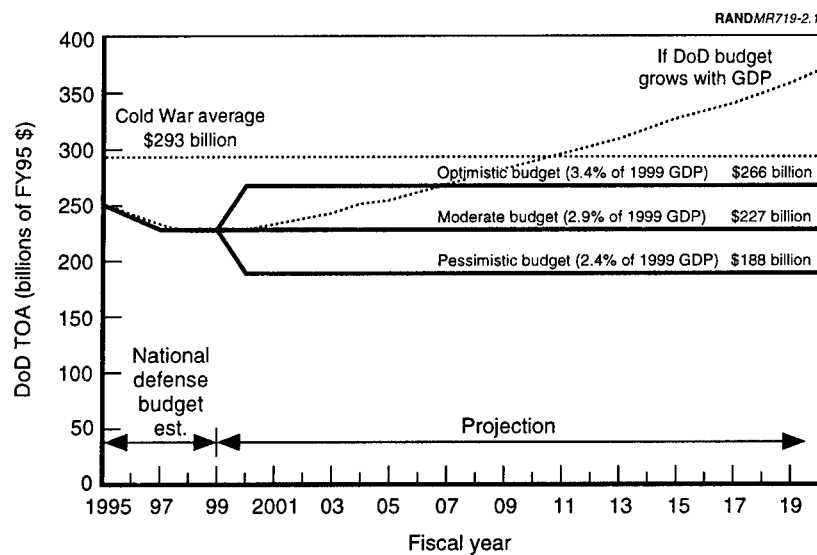
In conclusion, the F-16C/Ds will begin to reach the end of their 8000-hour service life between years 2010 and 2015. If the Air Force wants to maintain 20 fighter wings, it will need to buy a very large number of aircraft at rates in excess of 100 per year.

In this chapter we assess what the Air Force can afford to spend for a JSF given a spectrum of expected fiscal constraints. We establish three levels of future funding for Air Force fighter RDT&E by applying historical priorities for fighter modernization to projected DoD budgets. We also examine the effects on JSF affordability of reductions in the fighter force structure to fewer than 20 fighter wings, decreasing the F-22 buy from 4 fighter wings to 2 fighter wings, cost growth in the F-22 program, and competition from non-fighter Air Force programs. Reductions in force structure and F-22 buy have been examined only in terms of their impact on JSF affordability. We have not made any capability assessments.

In assessing affordability we establish the range of funding that might be available for aircraft modernization in general, and fighter modernization in particular, and then compare that with funding required to fulfill various about force structure size, mix, and aircraft cost alternatives.

### **ALTERNATIVE FUTURE DoD BUDGETS**

Figure 2.1 illustrates the alternative future DoD budgets we developed and carried through the analysis. DoD budget Total Obligational Authority (TOA) has been falling in real terms for most of the last decade. *National Defense Budget Estimates* suggests that the



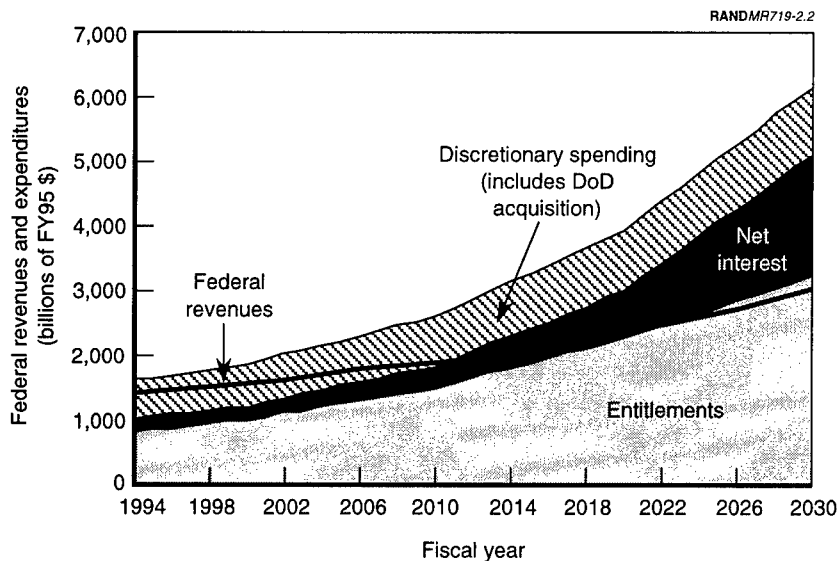
SOURCES: CBO and President's Budget.

Figure 2.1—Projected DoD Funding

decline may level off in the FY97 to FY99 time period.<sup>1</sup> We assumed that the budget remains constant at \$227 billion (\$ FY95) into the next decade, with variations of  $\pm 0.5$  percent of the projected FY99 Gross Domestic Product (GDP) around that value. We will refer to these budget levels as our pessimistic (\$188 billion), moderate (\$227 billion), and optimistic (\$266 billion) budget levels. All of these budget levels fall below the Cold War average (\$293 billion).

If, instead, DoD budgets grow with GDP, they would approach the Cold War average by the end of the next decade. Structural features of the federal budget call into question this kind of growth assumption. Figure 2.2 shows dimensions of the federal budget problem that are apparent in projections developed by the Bipartisan Com-

<sup>1</sup>Office of the Secretary of Defense, *National Defense Budget Estimates—FY95*, Government Printing Office, Washington, D.C.



SOURCE: Bipartisan Commission on Entitlement and Tax Reform, 1994.

Figure 2.2—Entitlements and Debt Will Constrain DoD Funding

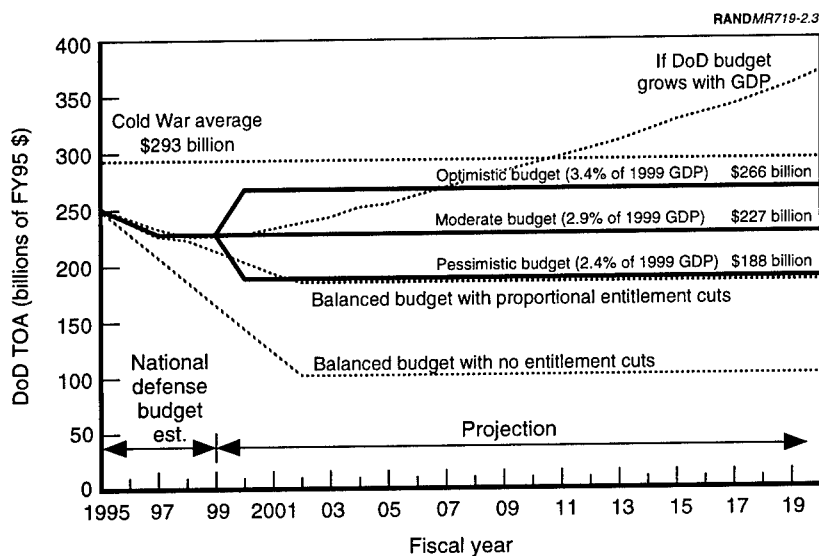
mission on Entitlement and Tax Reform.<sup>2</sup> Entitlements and debt-servicing costs are growing much faster than federal revenues, putting increasing pressure on federal discretionary spending accounts, including DoD funding for weapon system acquisition. This is true whether discretionary spending is assumed to be constant or to grow with GDP. Left unchecked, these trends could result in entitlements and debt servicing alone equaling federal revenues by the end of the next decade, with the situation worsening thereafter. We do not mean to imply this outcome will occur, but we use the example to demonstrate the severity of the fiscal budget problem.

<sup>2</sup>Bipartisan Commission on Entitlement and Tax Reform, *Interim Report to the President*, Superintendent of Documents, Washington, D.C., August 1994.

### The Effect of Budget Balancing Measures

The current Congress was unsuccessful in efforts to pass an amendment designed to force a balanced budget by 2002. Deficit reduction remains a major issue as Congress debates alternative approaches for trimming the deficit. Figure 2.3 illustrates how balancing the federal budget could influence DoD budget levels.

The impact of federal budget balancing measures on the DoD budget will depend on the relative share of spending cuts borne by discretionary accounts in general and DoD accounts in particular relative to cuts borne by entitlement accounts. Recently, Republicans in the House and Senate have offered balanced-budget proposals that do not involve any further cuts for the DoD budget beyond those already planned. However, at this writing, the policy blueprint for a balanced budget is very fluid, and at least two other cases provide benchmarks for possible impacts on the DoD budget.



SOURCES: CBO and President's Budget.

Figure 2.3—Effect of Balanced Budget on DoD Funding

If the federal budget were brought into balance by 2002, with entitlements and discretionary spending accounts (including DoD) sharing equally in the budget cuts, then the DoD budget might approximate the pessimistic level (\$188 billion) as shown in Figure 2.3. If instead, entitlement accounts were shielded from cuts and discretionary spending accounts had to bear the full burden of the cuts, then DoD budgets could fall to \$100 billion or less.<sup>3</sup> Although one should not infer a high degree of precision from these projections, it is clear that DoD budgets will be constrained for many years to come.

### **Modernization Funding Available with Declining Budgets**

To estimate the funding that might be available for modernization with declining budgets, we assessed the historical share of DoD budget TOA devoted to major Air Force fighter aircraft RDT&E and procurement (see Figure 2.4).<sup>4</sup>

Since funding priorities can change from year to year, we used not only average funding shares, but also standard deviations above and below those shares. Current RDT&E and procurement spending shares are both well below averages for the last two decades.

Coupling projections of DoD budgets with the historical information about total Air Force—and specifically fighter—aircraft budget shares yields a range of possible RDT&E and procurement funding projections for aircraft modernization. See Figure 2.5. From the ex-

<sup>3</sup>In the projection where the budget is balanced with proportional entitlement cuts, all budget categories except debt service are reduced by the percentage necessary to balance the budget. In the case where the budget is balanced without entitlement cuts, the discretionary budget components are cut disproportionately to the degree necessary to balance the budget. In both cases, the projections beyond 1999 assume that DoD spending is kept constant, and that tax revenue growth is sufficient to cover any future increases in entitlement spending.

<sup>4</sup>The shares were computed for the period between 1973 and 1990, to avoid distortions of the Vietnam War era and the transitional period after the end of the Cold War, in which a surplus of Cold War era aircraft could potentially distort steady-state spending patterns. They include RDT&E and procurement funding for major programs, but exclude Air Force funding for modifications.

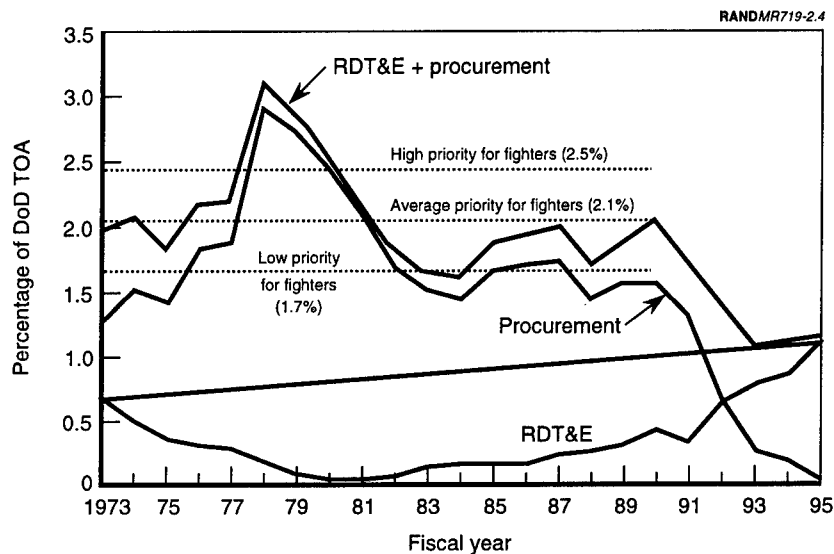


Figure 2.4—Historical Spending for Fighters

tremes of a low share of a pessimistic DoD budget to a high share of an optimistic DoD budget, one obtains a fighter funding spread of roughly \$3 to \$7 billion per year and a spread for all aircraft of roughly \$6 to \$15 billion per year.

If one discounts the optimistic projection for DoD budgets (because of pressures on discretionary spending within the federal budget), the range around the moderate DoD budget estimate is from \$3.8 billion to \$5.6 billion per year for fighters and \$6.9 billion to \$12.4 billion per year for aircraft overall.

## RECAPITALIZATION NEEDS

In the current budget cycle, large aircraft such as bombers and transports are receiving a greater share (or priority) of aircraft modernization funding than fighter aircraft. An examination of the Air Force's aircraft recapitalization needs suggests that the competition for limited aircraft modernization funds will continue.



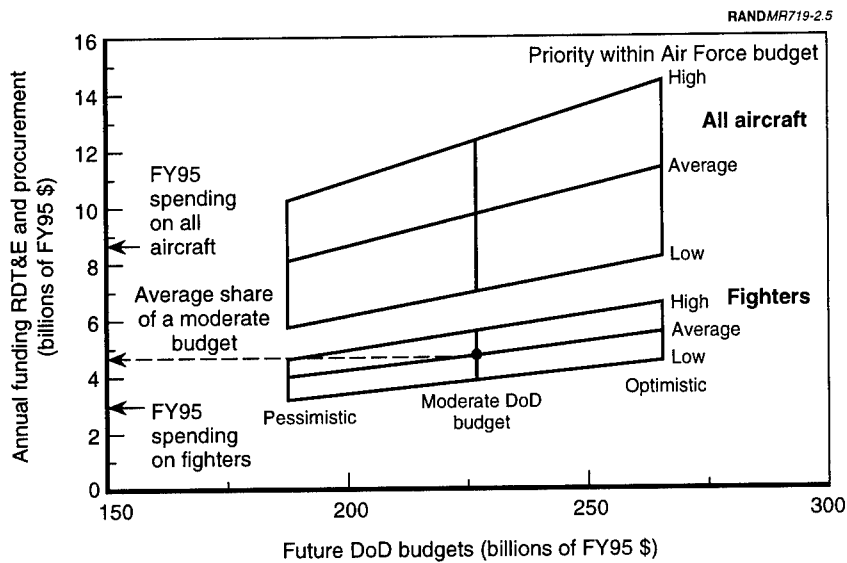


Figure 2.5—Probable Range of Funding of Fighter Modernization

Figure 2.6 shows that the steady-state funding level required to recapitalize all Air Force aircraft (that is, replace the aircraft as they reach the end of their useful life) exceeds probable aircraft modernization budgets. We estimated the research and development (R&D) and procurement costs to replace each aircraft type in the Air Force fleet, annualizing those costs based on the life of each aircraft type and its peacetime attrition. The figures show the average annual level of spending the Air Force must sustain to renew its fleet for three different cases. In the first case, every aircraft type within the Air Force is replaced on a one-for-one basis at development and procurement costs identical to the original aircraft (escalated to 1995 dollars), an optimistic assumption given historical cost growth patterns and the likelihood of reduced quantities for future buys. The annual cost for this case is slightly greater than the average share of the moderate DoD budget for aircraft modernization.

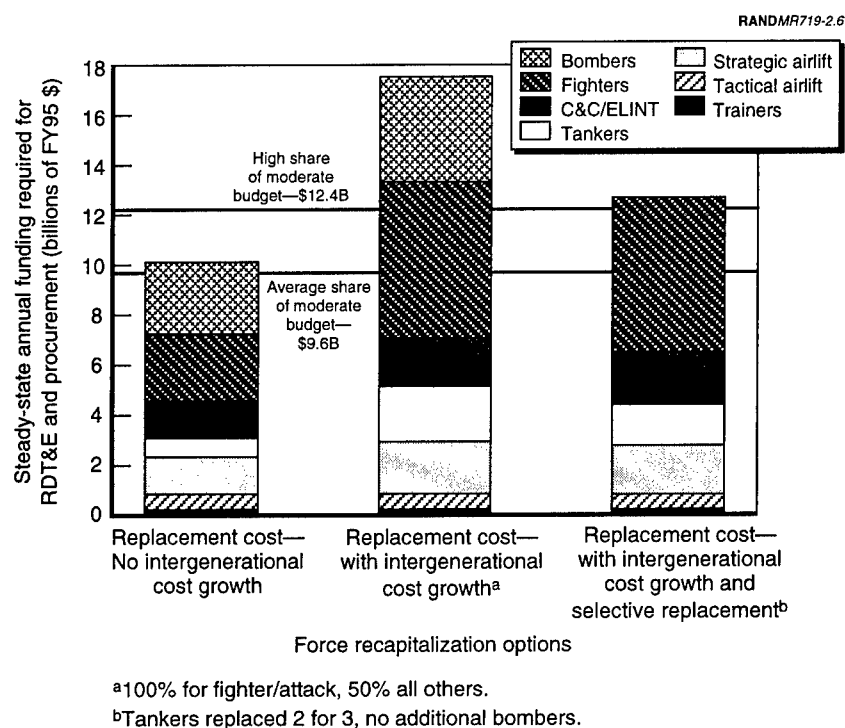


Figure 2.6—Recapitalization Needs May Exceed Modernization Budget

The second case assumes notional factors for intergenerational cost growth—100 percent for fighters, 50 percent for other aircraft types.<sup>5</sup> Aircraft are once again replaced on a one-for-one basis. Funding needs for this case exceed by a wide margin even high budget share (or priority) assumptions about funds available in a moderate DoD budget for aircraft modernization.

The second case may overestimate annual costs to recapitalize the fleet because next-generation systems should be more capable than current ones, and thus it may be possible to provide the same capability using fewer aircraft. For example, a modern tanker based on a

<sup>5</sup>For some derivative aircraft types, such as a C-130J, we assume only minimal intergenerational cost growth.

wide-body aircraft could provide a significant increase in fuel off-load capability over the narrow-body KC-135R tanker it would replace. In addition, the number of trainer aircraft may be reduced to reflect reductions in the force structure. Finally, certain components of the force may not be replaced in their current form, as a result of possible changes in concepts of operations, technology, or other developments.

The third case shown in Figure 2.6 assumes that the Air Force buys no more large bombers in the future and replaces tanker and trainer aircraft on a two-for-three basis. This case slightly exceeds funding levels for a high share of a moderate DoD budget.

The recapitalization costs of the Air Force are difficult to estimate with high confidence because of the amount of uncertainty in the future size and composition of the aircraft inventory. This task is further complicated by the inherent uncertainty in the costs of future systems. However, these comparisons demonstrate how the fighter/attack aircraft segment of the budget will continue to face considerable competition for funds from other aircraft types. This raises larger questions about the best overall mix of aircraft that the Air Force should maintain to meet its overall requirements in an affordable manner.

## FACTORS INFLUENCING JSF AFFORDABILITY

The price the Air Force can afford to pay for a JSF will be influenced by the cost of F-22s, the size of its total fighter force, the mix of JSFs and more-expensive fighter aircraft, and the amount of funding available for fighter modernization. Figure 2.7 illustrates the allowable JSF unit flyaway cost as a function of the cost of the F-22, size of the F-22 buy, and the size of the general purpose fighter force, assuming the Air Force has \$4.8 billion (\$ FY95) for fighter procurement per year (approximately an average share of the moderate future DoD budget).<sup>6</sup>

<sup>6</sup>These estimates also assume the Air Force expends funds to replace CONUS AD and FAC aircraft with JSF. For the calculations shown in the figure, the air defense requirement is assumed to be invariant to basic changes in the fighter force size, whereas the FAC need is assumed to scale with the parametric force structure excursions shown in the figure.

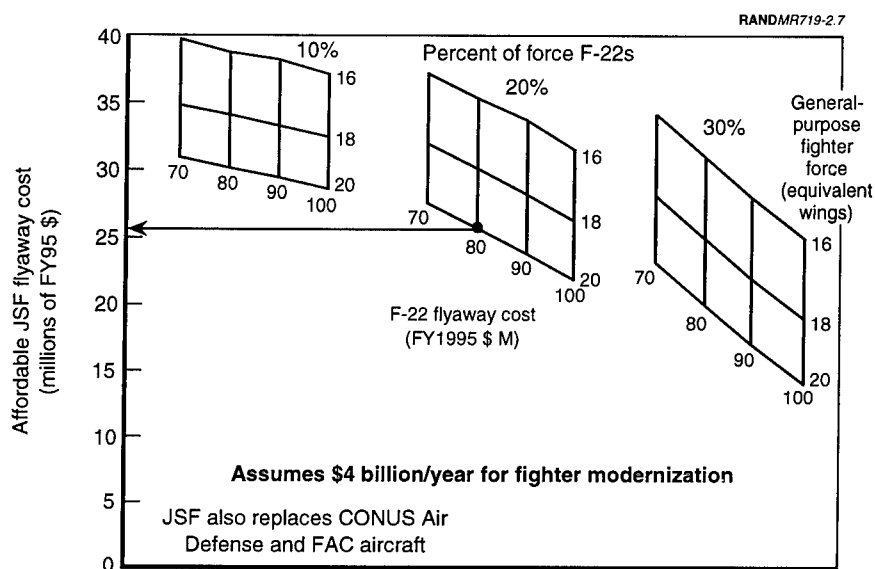


Figure 2.7—Effects of F-22 Cost and Force Structure on JSF Cost

## F-22 Costs

The current estimate for the flyaway cost of the F-22 is approximately \$70 million. Although we have treated the cost of the F-22 parametrically, we have highlighted a flyaway cost of \$80 million to reflect possible cost growth over the life of the program. This projection is based on the experiences of several other recent fighter programs. It translates to an allowable JSF flyaway cost of about \$26 million for a 20-wing force with four wings of F-22s—if the Air Force buys fewer F-22s—e.g., a silver bullet force with 10 percent F-22s—it could afford a \$30 million JSF within the \$4 billion procurement budget. If, instead, the Air Force decided it needed more F-22s or derivatives of F-22s (for example, to replace current interdiction aircraft), then fewer funds would be available for buying JSFs. If 30 percent of the force were F-22s, then the allowable cost of a JSF falls well below even the costs of current fighter aircraft. Another insight that can be gained from Figure 2.7 is the effect that JSF cost growth could have on the Air Force fighter force structure. Going back to the baseline, if

the JSF cost is \$26 million and the Air Force buys 4 wings of \$80-million F-22s, the Air Force can maintain 20 fighter wings. If, however, the JSF price were to grow to \$35 or \$40 million, the force structure could be maintained at only 16 or 14 fighter wings.

One should not definitively conclude from these examples that the Air Force cannot afford a JSF in the \$30 million range. However, to afford an airplane in this price range, the Air Force would have to fund fighter modernization at levels that substantially exceed those associated with a traditional fighter share of the lower DoD budgets expected in the future.

### **Fighter Modernization Funding**

Figure 2.8 illustrates how changes in the funding level for fighter modernization can influence the price the Air Force can afford to pay for JSFs, assuming in this example that F-22s cost \$71 million each (this assumes no additional cost growth in the program). At the \$4 billion level, approximating an average share of a moderate DoD budget, the allowable JSF cost ranges from about \$15 to \$33 million depending on assumptions about force structure size and the mix of F-22s and JSFs.

If fighter modernization gets a higher share of the budget for procurement, say \$5 billion per year, then the allowable cost of the JSF is roughly \$35 million per aircraft. Note that Air Force fighter modernization has received this level of priority within the DoD budget only three times in the last 24 years. To procure over 2000 JSFs needed to maintain the 20-fighter-wing force structure, the Air Force would need to sustain this level of funding for 10 to 15 years or more. These years would occur concurrently or just subsequent to completion of the F-22 buy.

Continuing pressures on the defense budget, such as those implied by a shift toward a balanced budget, may limit the amount of funds allocated to fighter modernization to \$3 billion per year. If this is the case, fighter force structure reductions or reductions in the F-22 buy would almost certainly be needed to afford a JSF.

The intent here is not to suggest a preferred force mix option, but rather to show relationships among some of the more important

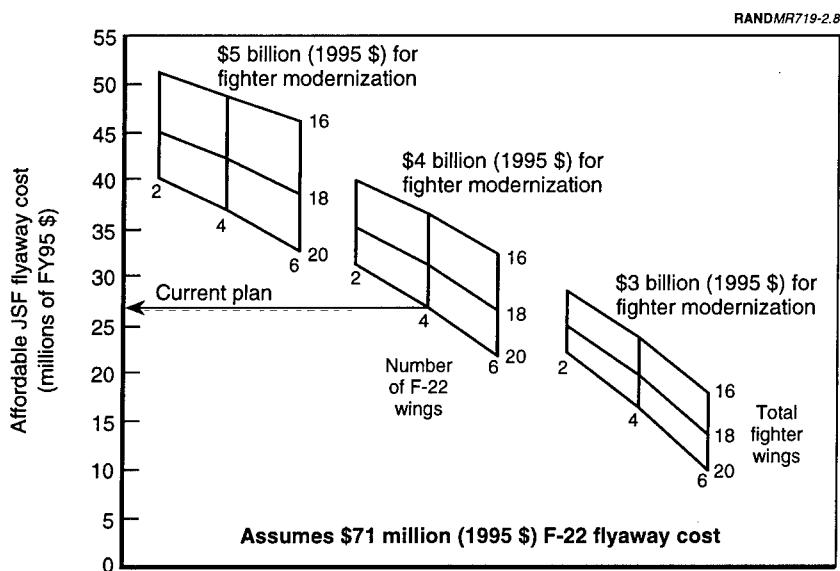


Figure 2.8—Effects of F-22 Buy and Force Structure on JSF Cost

decision-relevant variables. The results do suggest that the Air Force will have to attach a high priority to fighter acquisition funding and that it faces some difficult force mix decisions.

### Procurement Timing

In addition to the steady-state problems of funding the acquisition of F-22s and JSFs, the Air Force also faces some problems phasing expenditures for these two programs. If JSF is introduced in 2007, there will be several years in which the F-22 and JSF programs each require billions of dollars in funding. Shown in Figure 2.9 is the total funding required in those years. The overlap of the two programs creates a budget bow wave that may not be affordable. These funding requirements significantly exceed even a high fighter funding share of a moderate DoD budget for many years. If the F-22 schedule slips, this overlap in funding requirements increases.

Postponing JSF procurement can reduce the budget bow wave. A four-year postponement could reduce the funding peak to manage-

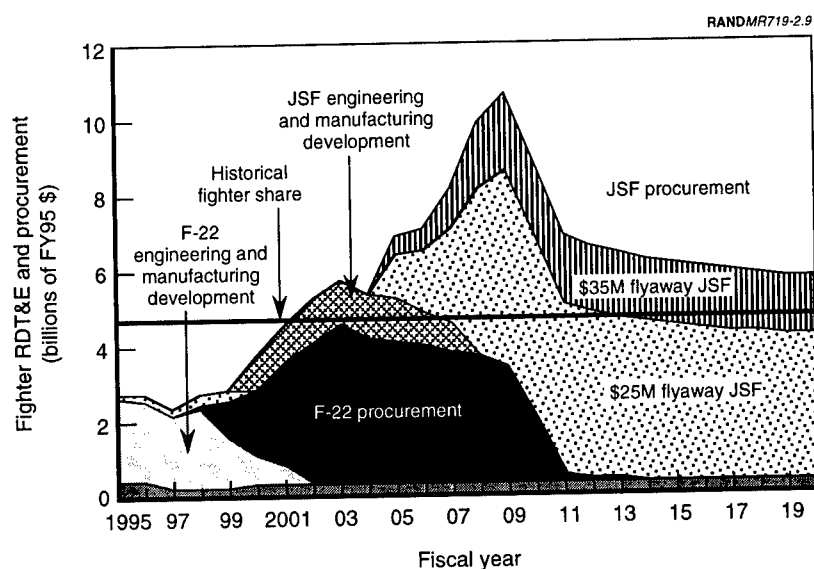


Figure 2.9—F-22 and JSF Procurement Creates Budget Spike

able levels, but, as Figure 2.10 illustrates, this approach has an adverse impact on force structure.<sup>7</sup>

Figure 2.10 shows that with no postponement in JSF procurement, a shortfall on the order of 100 aircraft could develop because of a lack of adequate attrition reserves in the current force structure. A two-year delay in JSF procurement could increase the peak shortfall to 150 aircraft and the duration of the shortfall to 12 years. With a four-year delay, inventory shortfalls could grow to 350 aircraft and force structure deficits could persist for more than two decades.

Some of the same policy options considered for eliminating the attrition shortfall also could push back the required introduction date

<sup>7</sup>As the number of active aircraft development and production programs dwindles, industrial base considerations loom larger in weighing the impacts of program postponements. Other Project AIR FORCE research is developing a framework for assessing how changes in funding influence military aerospace design and development capabilities.

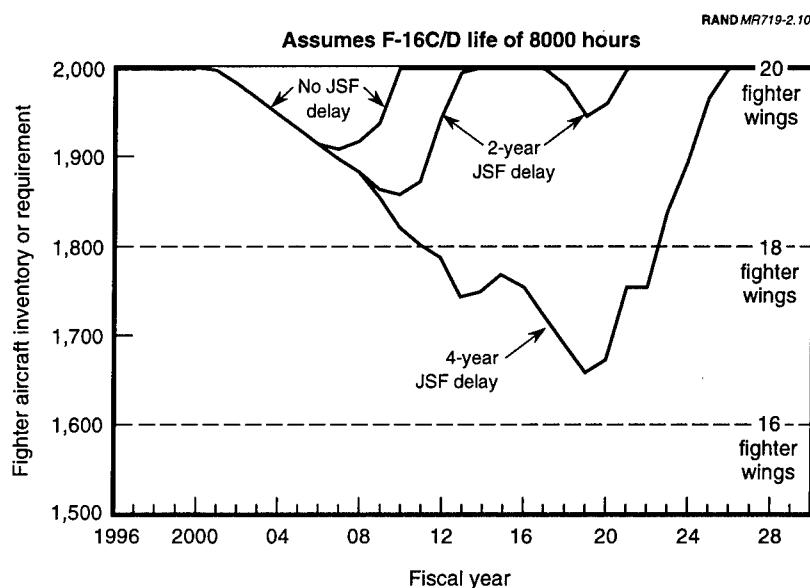


Figure 2.10—Effect of JSF Delay

for the JSF. Once again, these options include postponing the retirement of some older aircraft, buying more current aircraft, or accepting force structure reductions. The Air Force could extend the life of the F-16A/Bs through a service life extension program (SLEP). SLEP'ing F-16A/Bs to 8000 hours would resolve the attrition reserve problem and push off the required introduction date for the JSF but could cost \$3.7 billion (\$ 1995). In evaluating such aircraft retention options, one must weigh the benefits that might be gained from postponing the introduction of the JSF versus the continuing costs of keeping the older aircraft viable.

Buying 180 new aircraft from existing production lines could ameliorate the attrition reserve problem and push back the required introduction date of the JSF by approximately four years at a cost of \$4 to \$6 billion. The economic attractiveness of this option diminishes over time as production for foreign customers is completed and production rates decline.



Force structure reductions provide additional options. If the Air Force cut F-16 wings from its force structure *and* put those aircraft in its Backup Aircraft Inventory (BAI) to form a larger pool of aircraft over which to spread the required flying hours, it could push back the JSF introduction date to 2010 or beyond, depending on the size of the force structure reduction.

Note that here and elsewhere in this report, we examine alternative force structures only in terms of their impact on inventory requirements and affordability, not their influence on force capability. Force structure reductions could affect the Air Force's ability to support national military objectives.

## SUMMARY

In summary, the current environment poses many challenges for fighter modernization. Against a backdrop of declining or flat DoD budgets, intergenerational cost increases of aircraft are offsetting savings that might otherwise accrue from buying fewer aircraft for smaller force structures. Procurement accounts have declined significantly while infrastructure spending has not declined to the same degree. Fighter aircraft face strong competition for funds with other programs.

Based on historical priorities and projected DoD budgets, if the Air Force wants to maintain 20 fighter wings with 4 wings of F-22s, it can only afford a JSF with a flyaway cost of \$26 million. If the cost of the JSF is not constrained to \$26 million, then the Air Force will have to either increase the budget share for fighters by reducing spending elsewhere or reduce the force structure.

If the federal budget is balanced, increasing the pressure on discretionary spending and reducing the DoD and Air Force budgets, the Air Force will probably not be able to afford the airplanes necessary to meet future requirements in the quantities it desires. Modernizing to a 20-FWE force of F-22s and JSFs will require supplementing that traditional share of the budget for fighter acquisition by making trade-offs with other systems and accounts—perhaps changing the mix of aircraft and buying a JSF of substantially lower cost than currently contemplated.

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**COMBAT RADIUS NEEDS**

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In the next chapters of this report we examine several key operational characteristics of a new strike aircraft. Our purpose is not to “design a new aircraft” or to define the exact requirements that the services should use in the Mission Needs Statement (MNS) and Operational Requirements Document (ORD). In addition to this report, the services are receiving a broad spectrum of inputs from their own internal studies and from the airframe contractors. Our goal here is to provide an independent and objective analysis that the services can use, in conjunction with other analyses, in their development of the corresponding operational needs and requirements.

Several principles guided the analytic approach adopted to assess operational needs.

- Focus on those critical needs that could shape the ultimate design of the airplane and hence its cost and performance characteristics.
- Keep the analysis as transparent as possible, to make it easier to explain outcomes in terms of assumptions and inputs. Focus on identifying first-order effects on operational needs.
- Use models consistent in complexity with the current stage of the Joint Advanced Strike Technology (JAST) program. At this early stage in the program, use of overly detailed models may be unwarranted or imply a degree of precision or certainty that does not exist.

- Keep the analyses independent of specific aircraft configuration to enhance their general utility irrespective of particular contractor designs.

We begin by examining combat radius needs. Our analysis examines the mission radius needs for attacking fixed targets. While attacking armor and other missions are important, most of the fixed targets tend to be deeper and therefore set the radius requirements. As shown in Table 3.1, we examined the range requirement for three theaters (Iran, Iraq, and North Korea), three basing options (forward, fallback, and aircraft carriers), and three refueling options (no refueling, refueling on egress, and refueling on ingress and egress).

### REFUELING AND BASING OPTIONS IN THREE THEATERS

The theaters were chosen for their likely relevance to future missions and for the geographical demands they place on aircraft design. For the forward basing option, we selected existing military bases that were as close to the theater as possible. For fallback basing, we selected bases that were safe from theater ballistic missile (TBM) attack or from being overrun.

Radius estimates were calculated for all 27 combinations of theaters and basing and refueling options. In addition, we examined a case for attacking Iran where the carriers were stationed outside of the Persian Gulf in the Sea of Oman, and a case for attacking North Korea where the aircraft were based in Japan.

In all the cases, the radii represent the one-way distance to the target, from the point of last refueling. All radii reported here are great circle distances, and include a 30 percent increase to allow for avoidance of

Table 3.1

#### Theater, Basing, and Refueling Options Considered

Theater	Basing Option	Refueling Option
Iran	Forward	No refueling
Iraq	Fallback	1-way refueling
North Korea	Carrier	2-way refueling

NOTE: We also examined basing in Japan for the North Korean scenario.

air defenses and other operational factors that cause aircraft not to fly in straight lines from base to target. For example, an aircraft must be able to fly 650 nm in a straight line to attack a target 500 nm away from its base.

The maps shown in Figure 3.1 depict the three theaters in this analysis. As described in the legend, the dots are the targets from the Regional Conflict Model (RCM) data base. The crosses represent the airfields, the ovals represents the tanker orbit locations, and the aircraft carrier icons represent the carrier locations.

Carriers operated in the Yellow Sea and the Sea of Japan for the North Korean scenario. For the Iraqi scenario, we located carriers in the Red Sea and the Persian Gulf. For the Iranian scenario, we located the carriers in the Persian Gulf with a fallback to the Gulf of Oman. Carriers operated no closer than 100 nm from the forward edge of battle area (FEBA) or border or coast.

Tankers operated 100 miles behind the FEBA or border. We tried to place tanker orbits in safe areas roughly collinear with the targets and air bases. For the Iran and Iraq conflicts, we assumed no partic-

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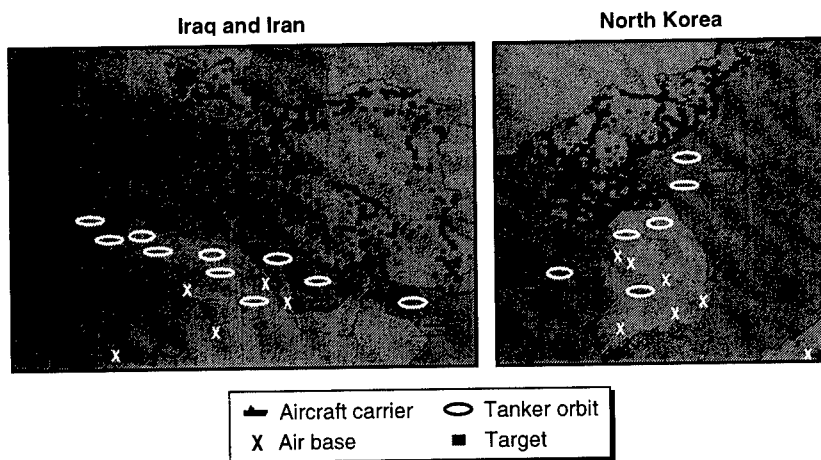


Figure 3.1—Distribution of Targets and Attack Assets

ipation from Turkey or Israel and no overflight rights from the Mediterranean Sea. For the Iran conflict, we assumed no overflights of Pakistan or Afghanistan.

Figure 3.2 shows the cumulative probability that a target is within a given range (to a launch point) in South Korea or Japan. The case shown does not include in-flight refueling. For an aircraft to potentially hold 100 percent of the targets in North Korea at risk without in-flight refueling, it needs approximately 650 nm of radius with forward basing, and 700 nm radius with fallback basing. For basing in Japan, aircraft need 1135 nm radius to keep 100 percent of the targets at risk without refueling.

The Iranian theater is the most stressing with respect to range requirements. Figure 3.3 shows the cumulative probability that a target is within a given range for aircraft based in southern Saudi Arabia.

To avoid overstating the range requirement, we considered the contribution of other U.S. strike assets in the theater. For example, if

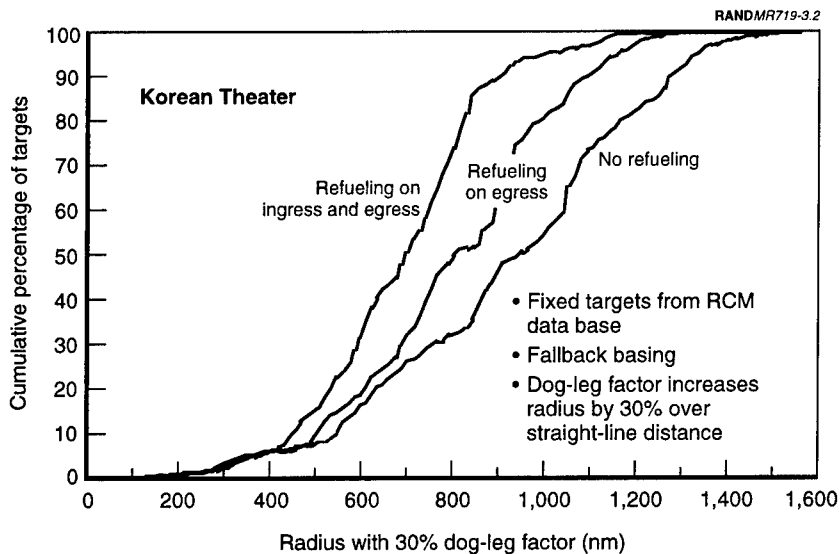


Figure 3.2—Korean Target Radius Distribution

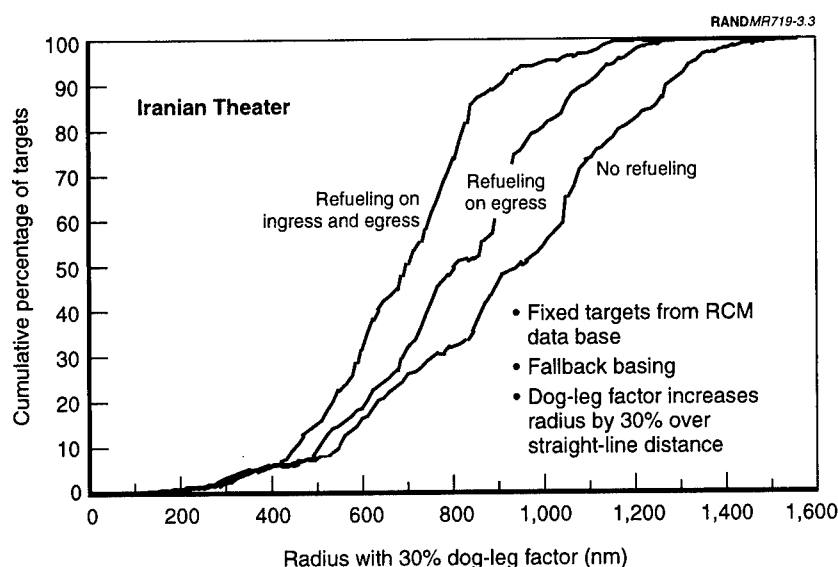


Figure 3.3—Radius Distribution of Iranian Targets

Tomahawk Land-Attack Missiles (TLAMs) from carrier battle groups and the heavy bomber force attack the deeper targets, the JSF may not need to hold all the targets at risk. TLAMs from one carrier battle group and three days of attacks by heavy bombers might destroy roughly 10 percent of the targets. To keep the remaining 90 percent of the targets at risk without refueling, JSF needs a radius of 420 nm with forward basing and 530 nm with fallback basing. TLAMs from three carrier battle groups and seven days of heavy bomber sorties might destroy roughly 30 percent of the targets. The radius requirement to hold the remaining 70 percent of the targets at risk is 320 nm with forward basing and 410 nm with fallback basing.

Figure 3.4 shows the radius requirements to reach 70 percent, 90 percent, and 100 percent of the targets in the three theaters with favorable basing and no refueling. With favorable basing, a new aircraft with 650 nm radius can reach 70 percent of the targets in any theater without refueling.

We next examined the impact of less-than-favorable basing on the radius requirement. Figure 3.5 illustrates the radius requirements for

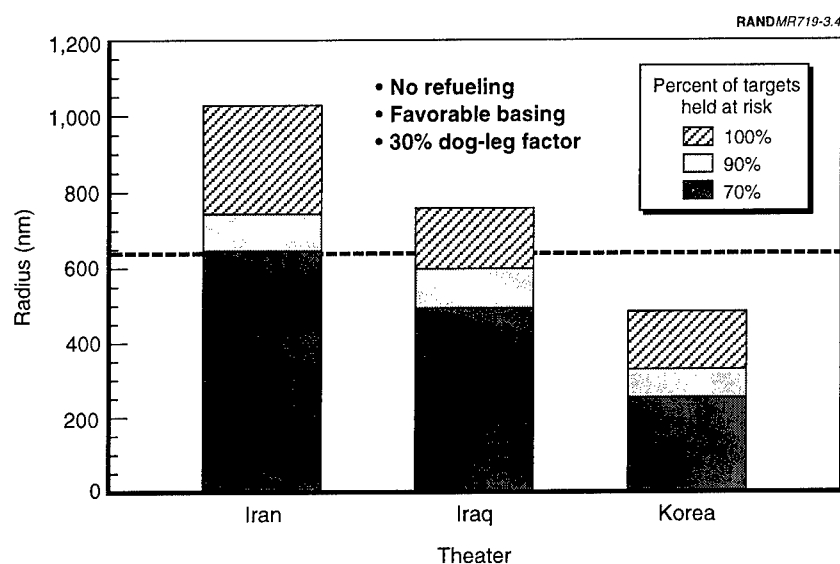


Figure 3.4—Radius Requirements with Favorable Basing

the three theaters and the different basing options. One way to read Figure 3.5 is to enter the chart from the left-hand axis and read, from the graphic, the refueling requirement. For example, if a new aircraft has a radius capability of 650 nm, it would not require any refueling to reach 70 percent of the targets in either North Korea or Iraq, regardless of the basing option. For the Iran scenario, an aircraft with 650 nm radius would require only in-flight refueling for the fallback basing and for basing on carriers.

Based on this analysis, we believe an aircraft with an effective radius of 650 nm is probably sufficient for the JSF. An aircraft with a radius of 650 nm can reach 70 percent of the targets in all three theaters with favorable forward basing, and, with some in-flight refueling, can reach 70 percent of the targets with fallback basing.

Increasing the aircraft radius to 700 nm would not substantially decrease the requirements for in-flight refueling. Increasing the radius to 700 nm would only affect aircraft flying from carriers in the Iranian scenario. A radius of 800 nm or more would be required to

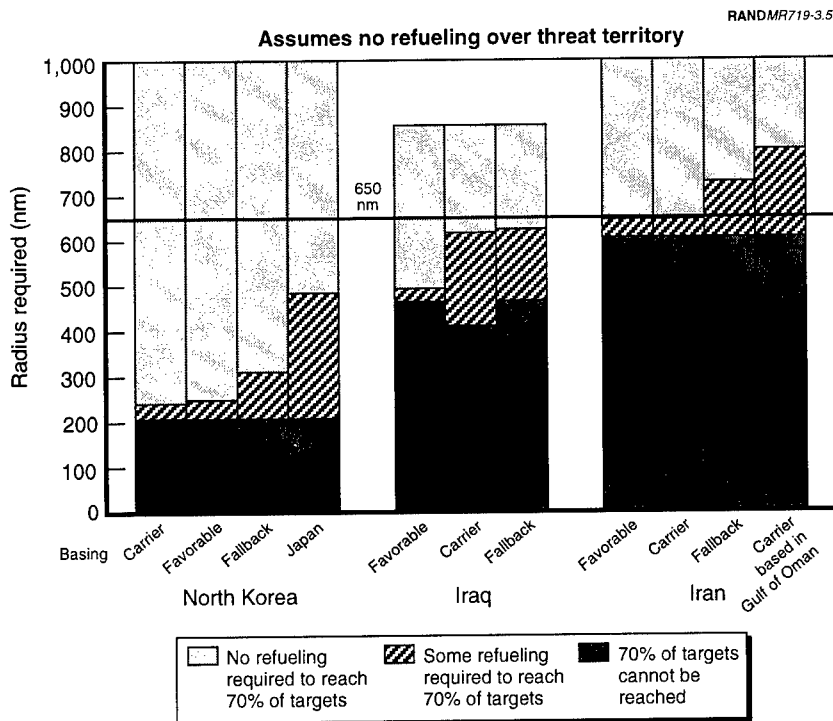


Figure 3.5—Radius Requirements

significantly decrease the dependence on in-flight refueling. Decreasing the radius requirement from 650 nm to 600 nm would significantly increase the dependence on in-flight refueling. With a radius of only 600 nm, aircraft flying from carriers outside the Gulf would not be able to reach 70 percent of the targets even with two-way refueling. With only 600 nm of radius, both land- and carrier-based aircraft target attack capabilities are adversely affected. Decreasing the range requirement below 650 nm would require greater reliance on the heavy bomber force and TLAMs launched from carrier battle groups.



## COST IMPLICATIONS

Finally, we examined the cost implications of various radius requirements. Shown in Figure 3.6 is a nomograph that links the JSF target coverage with the flyaway cost. The second quadrant (upper left) links the target coverage with the radius requirements. The heavy bombers and TLAMs, from carrier battle groups, can hold the farthest 30 percent of the fixed targets at risk. If the JSF has to hold the other 70 percent of the fixed targets at risk in any theater (Iran being the most stressing), then the JSF needs about 650 nm of radius. The first quadrant (upper right) links the aircraft radius with aircraft empty weight. The three lines in this quadrant are for three different design concepts. In Chapter Six, we will address the weight and range penalty should the Air Force buy a derivative of STOVL (short takeoff, vertical landing) or carrier-suitable aircraft. To achieve a maximum aircraft radius of 650 nm with a derivative of a STOVL or

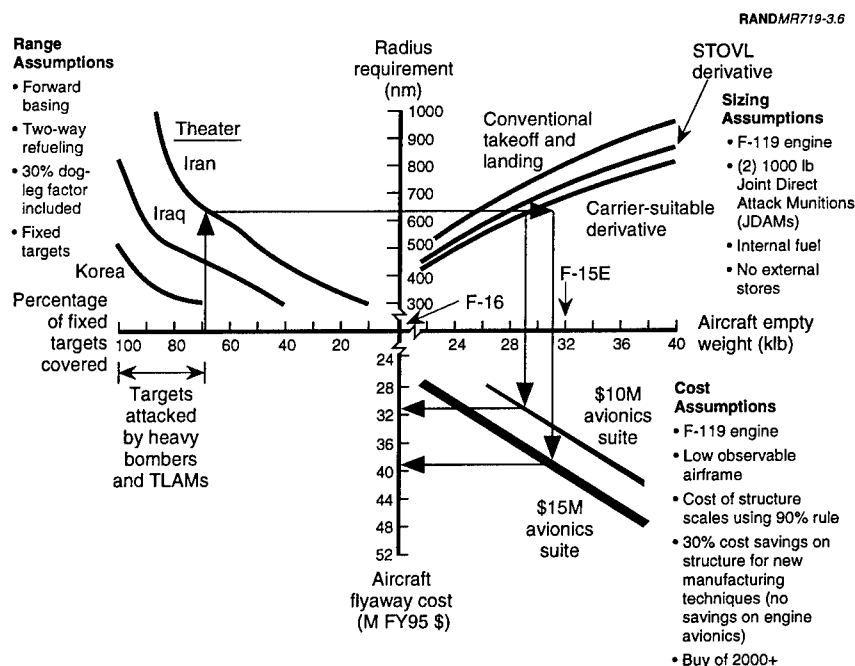


Figure 3.6—JSF Range-Versus-Cost Nomograph

carrier-suitable aircraft, an aircraft with an empty weight of 29,000 to 31,000 lb is required. Aircraft empty weight is a good surrogate for aircraft size. A 29,000 to 31,000 lb aircraft is closer to the size of an F-15E than it is to an F-16C. Unfortunately, as shown in the fourth quadrant (lower right), the cost of a new 30,000 lb aircraft, with a \$15 million avionics suite, is in the \$35–\$40 million range (flyaway). A \$15 million avionics suite has several long-range sensors that would allow the JSF to search out and find most targets. A \$10 million avionics suite will have to depend on off-board assets for much of its targeting. As discussed in Chapter Two, the Air Force cannot afford a \$35–40 million aircraft. The Air Force can only afford a \$26–\$28 million aircraft. Returning to Figure 3.6 but working in the opposite direction, a \$26–\$28 million aircraft will be closer to the size of an F-16C (with an empty weight between 18,000 and 26,000 lb). An aircraft of this size will have a flight radius of only 400 to 500 nautical miles. Unfortunately, a 400 to 500 nm aircraft does not have the target coverage the Air Force needs. If, however, the JSF is built with a \$10 million avionics suite, the Air Force can afford a larger aircraft that will provide more range and therefore better target coverage.

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## STEALTH AND STANDOFF WEAPON TRADE-OFFS

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In this chapter we examine the relationship between radio frequency (RF) stealth, standoff weaponry, and mission effectiveness. Stealth is one of the principal reasons the services may need a new aircraft instead of a derivative of an existing design. It is difficult and expensive to modify an existing design to achieve the same level of stealth a new design would have. The stringency of stealth requirements may determine whether derivatives of the F-15E, F-16C, and F-18E/F can compete to satisfy the JSF need. This chapter is not intended to be a definitive work on stealth, but to provide a perspective of the required levels of RF stealth in possible future regional conflict scenarios.

Our examination of stealth is divided into three analyses. In the first analysis we examine the stealth required for medium-altitude attacks on fixed targets defended by an Integrated Air Defense System (IADS). The second analysis examines an interdiction attack on an armored column defended by tactical Surface-to-Air-Missiles (SAMs). The third analysis examines the effects of stealth on the outcome of a representative air-to-air engagement.

### ATTACKS ON FIXED TARGETS

In this section we examine the relationship between RF stealth and the use of standoff weaponry in the JSF's ability to attack with impunity fixed targets from medium altitude (probability of survival 100 percent). Medium altitude was chosen to eliminate the possibility of engagement by highly mobile and highly proliferated classes of short-range and man-portable SAMs as well as anti-aircraft artillery

(AAA). The trade-off between stealth and standoff was examined for attacking fixed targets defended by a strategic IADS as well as mobile targets defended by tactical SAMs.

The probability of survival must be very high to keep aircraft losses from severely reducing the fighter inventory in a long campaign. In addition, the public is likely to be sensitive to casualties in a regional conflict. For these reasons, a probability of survival of unity was selected as our criterion for this analysis. In terms of the methodologies used, this criterion means that SAMs may be launched at the aircraft, but those launched will fail to intercept.

Figure 4.1 presents the variations in radar cross section (RCS) we examined in this study. We examined nine stealth concepts, which we grouped into three broad categories.

The three levels of RCS considered represent different levels of effort in achieving stealthiness, and are characterized by different levels of suppressed signature. The first, which we call “Low Stealth Fighter,” represents two different concepts. One concept would retrofit as much stealth as possible onto an existing platform; the other is a new design where few compromises were made during the design process to reduce the RF signature. The “Moderate Stealth Fighter” represents a new aircraft design where some design compromises were

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Low Stealth Fighter	Moderate Stealth Fighter	High Stealth Fighter
<ul style="list-style-type: none"> <li>• New aircraft design not required</li> <li>• Existing aircraft can be modified to achieve this level of stealth</li> <li>• New designs would require few compromises to achieve this level of stealth</li> </ul>	<ul style="list-style-type: none"> <li>• New aircraft design required</li> <li>• Some design compromises required to achieve stealth</li> <li>• Weapons bay required but electronically steerable antenna probably not necessary</li> </ul>	<ul style="list-style-type: none"> <li>• New aircraft design required</li> <li>• Strong concentration on low observability during aircraft design process</li> <li>• Many design compromises required to achieve stealth (e.g., internal weapons storage, electronically steerable antenna for the radar)</li> </ul>

Figure 4.1—Stealth Concepts Examined

made for stealth but stealth was not the primary design “requirement.” This concept would require a weapons bay but probably would not require a stealthy electronically steerable radar antenna. The “High Stealth Fighter” represents a concept where a strong concentration was placed on RF observability during the design process.

Each of these concepts was examined in the three theaters. In each theater, the air defense and target lay-downs are for the year 2010. The broad characteristics of the theaters are shown in Figure 4.2.

While the air defenses in these scenarios are extensive and pose a significant threat, particularly to conventional aircraft, they are not present in the densities expected against Cold War threats such as the Warsaw Pact or the Soviet Union. The North Korean threat is extensive, but not very modern. The threats in Southwest Asia are sophisticated, but cover limited geographical areas.

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Characteristic	Iran	Iraq	North Korea
Air Defense	<ul style="list-style-type: none"> <li>• Large undefended areas</li> <li>• Groups of SAMs surrounding some targets</li> <li>• Many targets hard but undefended</li> </ul>	<ul style="list-style-type: none"> <li>• Defenses around major cities</li> <li>• Groups of SAMs surrounding some targets</li> <li>• Most targets are defended</li> </ul>	<ul style="list-style-type: none"> <li>• Defense SAM environment</li> <li>• All targets are defended</li> </ul>
Surface-to-Air Missiles	<ul style="list-style-type: none"> <li>• Moderate number of a mix of older and newer SAMs</li> </ul>	<ul style="list-style-type: none"> <li>• Moderate number of a mix of older and newer SAMs</li> </ul>	<ul style="list-style-type: none"> <li>• Larger number of older SAMs</li> <li>• Very few newer SAMs</li> </ul>
Air Force	<ul style="list-style-type: none"> <li>• Moderate number of newer U.S. fighters and modern Russian fighters</li> </ul>	<ul style="list-style-type: none"> <li>• Moderate number of newer and modern Russian fighters</li> </ul>	<ul style="list-style-type: none"> <li>• Large number of older Russian fighters</li> </ul>
Command and Control	<ul style="list-style-type: none"> <li>• Poor</li> </ul>	<ul style="list-style-type: none"> <li>• Poor</li> </ul>	<ul style="list-style-type: none"> <li>• Moderate</li> </ul>
Training	<ul style="list-style-type: none"> <li>• Poor</li> </ul>	<ul style="list-style-type: none"> <li>• Poor</li> </ul>	<ul style="list-style-type: none"> <li>• Moderate to poor</li> </ul>

Figure 4.2—Theaters Examined

However, both Iran and Iraq possess sufficiently modern air defense systems to place their most important targets within a ring of overlapping SAMs of the highest quality. These defenses may make attacking these targets prohibitively costly to attack without stealth, but their limited geographic coverage means they may be attacked with standoff weapons of adequate range.

Figure 4.3 gives an example of the one-on-one, single-shot, SAM Pk (probability of kill) footprints that were generated for all aircraft signatures against all SAM types in the scenarios using the ESAMS program. The cells in these envelopes are shaded to represent locations where the Pk resulting from a SAM launch (when the aircraft is at that particular location relative to the SAM site) is not zero (i.e., where the aircraft is at risk of being hit). The aircraft flight trajectory is straight down the page. These examples demonstrate clearly the impact that increasing levels of aircraft stealth have on the capability of a typical SAM system.

These single-shot Pk's were combined with intelligence data on SAM firing doctrine and engagement delay times to compute cumulative Pk timelines for aircraft flybys of the SAM site at constant offset distances. The cumulative Pk footprints of all SAM sites in each scenario were combined onto a single grid using the COMPOSITE program developed at RAND.

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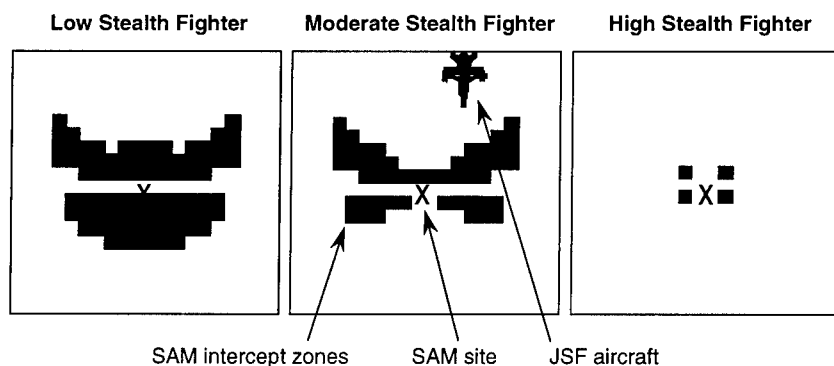


Figure 4.3—SAM Kill Probability Footprints

Figure 4.4 shows an example of the results of the COMPOSITE grid calculation for the SAMs in the Iraqi scenario. The Pk footprints in COMPOSITE are limited by the detection range of the SAM acquisition radar (which is assumed collocated with the firing unit). The resulting grid has values corresponding to the cumulative Pk experienced from all SAMs for an aircraft flying through that grid point. The maps show the composite SAM coverage in the theater against the indicated signature, with an outline of the country shown for reference. The shading represents locations where there is a risk of losing an aircraft penetrating to that point. Since our criterion was a probability of survival of 1, these areas are considered keep-out zones for the purposes of our target coverage analysis.

The location of each target in the RCM data base were placed on the composite grid. Each target was examined to see if an aircraft could reach a weapon delivery point within a specified standoff range from the target and retain a probability of survival of unity ( $P_k = 0$ ).

Shown in Table 4.1 are the significant characteristics of the three main ground attack weapons currently in development; current generation laser-guided bombs are also shown. These new weapons will likely form the primary armament of the JSF.

A range of 0 nm was selected in the stealth analysis, representing the need to directly overfly the target, which is consistent with the current generation of weapons. The next range examined was 5 nm,

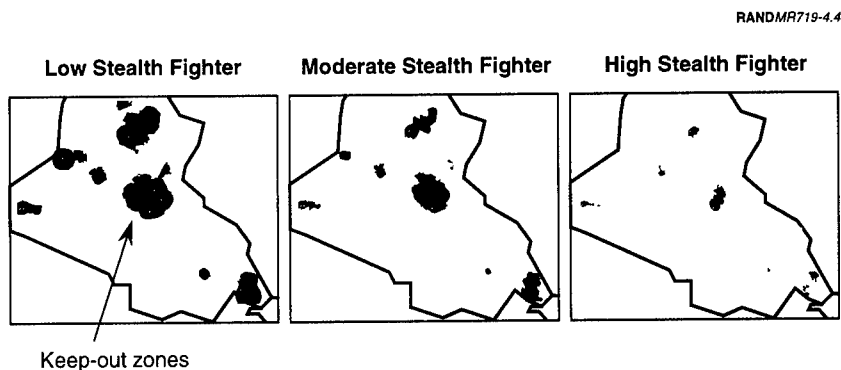


Figure 4.4—Iraqi SAM Coverage

**Table 4.1**  
**Standoff Weapons Examined**

Standoff Weapon	Standoff Range (nm)	Warheads	Cost (95 \$K)	Planned Buy
Laser-guided bomb	0	Unitary	~50	>10,000
Joint Direct Attack Munition (JDAM)	~5	Unitary	~20	>10,000
Joint Standoff Weapon (JSOW)	~15–30	Unitary Submunitions	~200	~3,000
Joint Air-to-Surface Standoff Missile (JASSM)	>100	Unitary Submunitions	~700	~2,400

representing the standoff that can be achieved with a weapon like JDAM. Because of its accuracy and relatively low cost, JDAM will be the primary JSF weapon. Finally, standoff ranges of 15 and 30 nm were selected, both of which are likely to be within the capabilities of the JSOW when released from medium altitude. However, because of the high cost and small inventory of JSOW when compared to JDAM, any design concept that requires JSOW usage to survive will have limited utility. Since the JASSM is being designed for launch from outside of area defenses, its capabilities were not considered in this analysis.

For each of the theaters, we examined the standoff range necessary to attack the fixed targets with impunity (probability of survival of 100 percent) against the IADS. We eliminated the heavily defended targets that the heavy bombers and TLAMs (from carrier battle groups) would attack. We examined cases with three, seven, and ten days of heavy bombing and TLAMs from one and three carrier battle groups. Finally, we included the effects of a SEAD (suppression of enemy air defenses) campaign.

Figure 4.5 summarizes the results of the target coverage analysis for all three theaters. The three theaters have broadly similar results; no one scenario dominates the makeup of the overall matrix. The results are presented as a matrix of the day of the war versus standoff range, with the boxes coded to indicate what level of stealth is required to attack the target set with impunity under those



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Standoff (nm)	Day of Conflict			
	1	3	7	10+
0	HSF	HSF	MSF	LSF
5	HSF	MSF	MSF	LSF
15	MSF	MSF	LSF	LSF
30	LSF	LSF	LSF	LSF

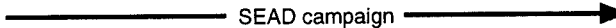


Figure 4.5—Stealth and Standoff for Attacking Fixed Targets

conditions (HSF = high stealth fighter, MSF = medium stealth fighter, and LSF = low stealth fighter).

This analysis indicates that with the presence of an ongoing SEAD campaign, high levels of stealth are required only for attacking fixed targets early in the conflict, and primarily when using weapons that require direct overflight. A moderate level of stealth, combined with the use of JDAM-type weapons, can address the majority of the target set, even early in the war. The remaining heavily defended targets can be attacked by other platforms or through the use of longer-range standoff weapons.

## INTERDICTIONING AN ARMORED COLUMN

Figure 4.6 depicts the mobile target attack mission scenario. The target is an armored column, which may be defended by short-range organic defenses as well as longer-range SAMs. As with the fixed targets, a medium-altitude attack was postulated; it avoids the organic defenses, limiting the threat to that posed by the area defenses. The location of these area defenses relative to the target was a variable in this analysis. An assumption in this scenario is that the column can be effectively targeted and attacked by the JSF from medium altitude.

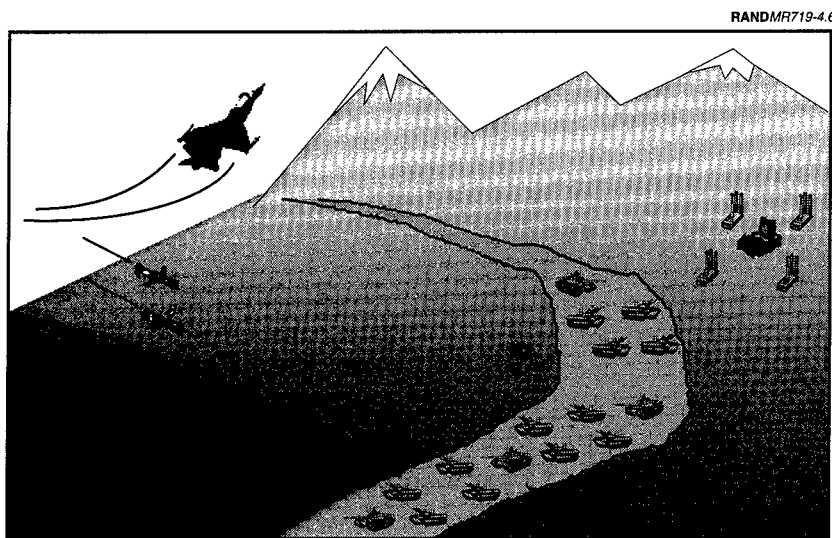


Figure 4.6—Interdiction Mission

In this traditional time-line analysis, the aircraft approaches the targeted column. At some point it may be detected by the defending SAM's radars. The aircraft reaches the standoff range required for weapon release, releases its weapon, and begins a turn to egress. Meanwhile, after an engagement delay time, the SAM site launches a missile at the aircraft. The aircraft's goal is to deliver its weapon, turn, and egress out of range before the defending SAM can intercept.

This analysis examined two types of threat, medium range and long range. Standoff ranges considered were none (current generation cluster bomb units [CBUs], for example), 5 nm (JDAM or wind-corrected munitions dispenser [WCMD]), and 15 nm (JSOW). Longer standoff ranges were not considered because other analysis at RAND indicated that weapon effectiveness was considerably degraded at longer standoff ranges because of target movement during the weapon's time of flight.

The results for the medium-range SAM are presented in Figure 4.7 as the signature required to prevent SAM intercept versus SAM location

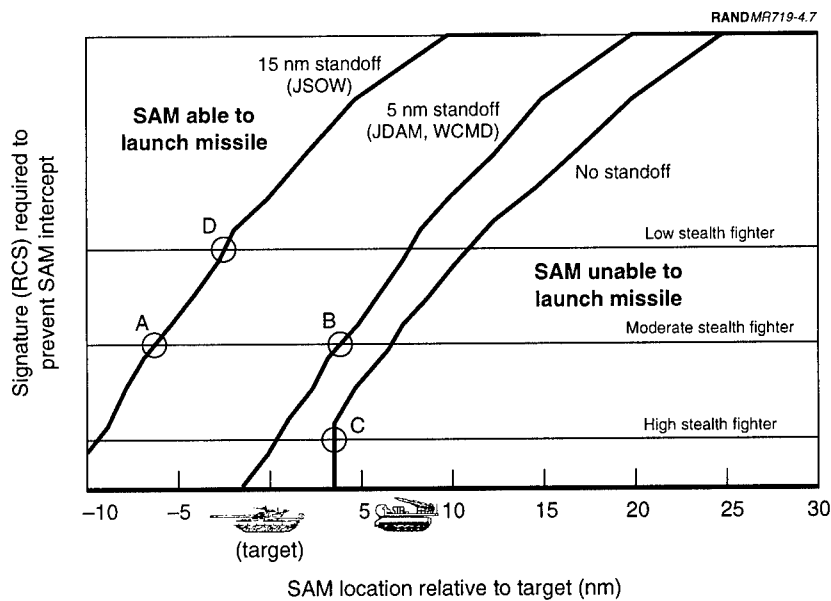


Figure 4.7—Interdiction Results for Medium-Range SAM

relative to the target, in this case for the medium-range threat. Normally, the air defense will leapfrog the armored column—first setting up in front of (or just behind) the armored column and then after the armored column has passed, tearing down and moving in front of (or just behind) the armored column again. In Figure 4.7, if the SAM location is negative, the air defense is in front of the armored column. Since the air defense is vulnerable to ground fire (from advanced artillery systems etc.), it rarely moves very far in front of the armored column. Many countries keep their air defense system between 5 nm and 10 nm *behind* the armored column. This makes the armored column vulnerable to even a moderately stealthy aircraft. Obviously, there is no point in having an air defense system if it is not protecting the armored column. If the air defense system is moved into a position where it can protect the armored column against a stealthy aircraft (i.e., in front of the armored column), it is extremely vulnerable to other types of attack.

Lines showing the RCS required to prevent intercept are given for the three standoff ranges considered. Also shown are the relative RCS levels for the low, moderate, and high stealth fighters.

Figure 4.7 suggests that with a JSOW (~15 nm standoff) a moderately stealthy JSF (Point A) can attack an armored column unless the air defense is pushed more than 5 nm forward of the armored column. However, the effectiveness of the Sensor Fuzed Weapon (SFW) will decrease with a long time of flight without a terminal seeker on board the JSOW. If the air defense is more than 5 nm behind the armored column, a moderately stealthy JSF can attack the column with only 5 nm of standoff (Point B). The high stealth fighter can almost always attack the armored column with little or no standoff (Point C). The low stealth fighter would need to stand off with a JSOW to attack an armored column protected by a modern air defense system.

Note that aircraft altitude is not explicitly played in these calculations. If one wanted to represent a low-altitude attack, the SAM would no longer be able to attack the aircraft when the target is beyond the range of the radar horizon. However, at low altitude the aircraft would also have to face the armored column's organic short range defenses.

The results of the interdiction mission are roughly the same as for attacking fixed targets (i.e., neither the fixed target attack nor the interdiction mission dominate the stealth requirements). If the JSF must overfly defended targets, it needs to be a high-stealth fighter. The JSF needs to be only a moderately stealthy fighter if it can stand off 5–15 nm. A low-stealth fighter needs to stand off 15 nm until the air defense is degraded. In addition to requiring more-expensive weapons, additional standoff could require a more-expensive avionics suite for targeting and secure communications with the weapon.

## AIR-TO-AIR ENGAGEMENT

In this section we examine the effect of stealth on the outcome of a representative air-to-air engagement. As shown in Figure 4.8, four JSFs penetrate enemy air space; they are equipped with air-to-ground ordnance and air-to-air missiles (two AIM-9Xs, and two AIM-120Cs). The JSFs penetrate at .9 Mach at an altitude of 20,000 feet.

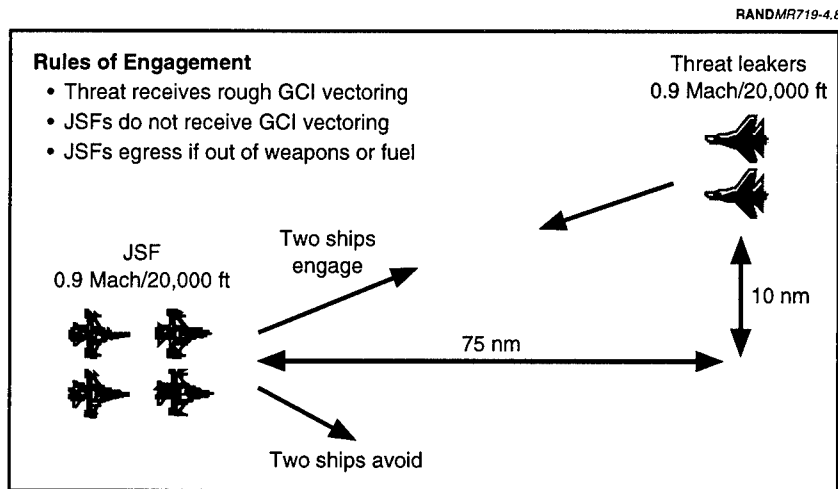


Figure 4.8—Air-to-Air Engagement

There are two threat interceptors 75 nm away that have “leaked” through the escorts and are receiving ground-control-intercept (GCI) vectoring on a collision course with the JSFs. The JSFs are not receiving GCI vectoring. As soon as a JSF detects the interceptors, two JSFs engage the interceptors and two JSFs attempt to avoid the interceptors and proceed to their targets.

Given the similarity between the F-16C and JSF roles, we assumed the services would want a JSF with at least the same margin of superiority (in air-to-air combat) over its intended threat as the F-16C has over today’s threat. The JSF was assumed to have a F-119 engine and a level of turn-rate performance consistent with an advanced multirole aircraft. The avionics on the JSF were the same for all three JSF stealth concepts. They were equipped with a radar similar to an APG-68. For defensive avionics, we equipped them with a radar warning receiver, flares, chaff, and electronic countermeasures. We used version 6.15 of the Tac Brawler air combat model for this analysis, and assumed all pilots to be of equal ability.

Shown in Figure 4.9 are the results of this engagement. The horizontal axis shows the F-16C, as a point of comparison for this engagement, and the three JSF concepts. Up along the vertical axis is the

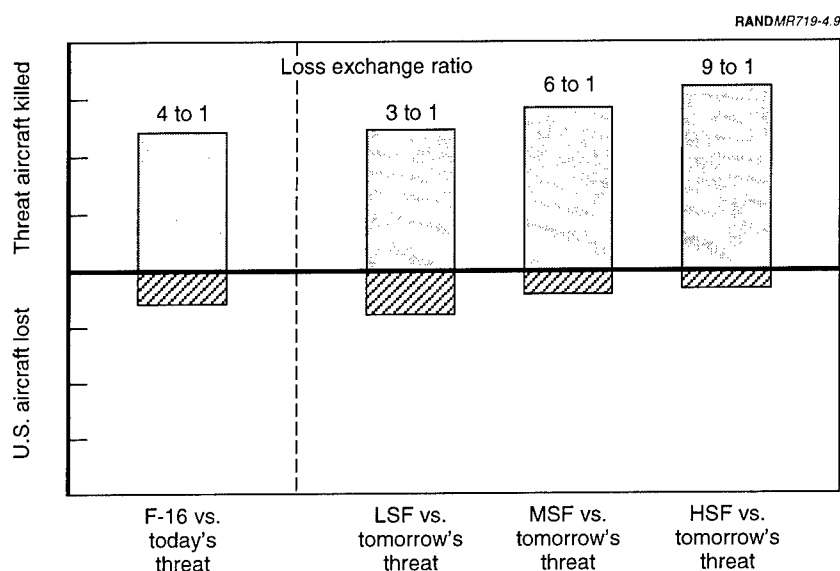


Figure 4.9—Air-to-Air Engagement Results

number of threat aircraft killed. Down on the vertical axis is the number of U.S. aircraft killed in this engagement. At the top of each bar is the loss exchange ratio.

For this engagement, today's F-16C has a loss exchange ratio of about 4 to 1 versus today's threat because of its superior avionics and weapons. Most of the F-16Cs were lost in close-in combat. If the F-16C were equipped with a helmet-mounted sight (HMS) and an AIM-9X capability, it would have fared better.<sup>1</sup> In this scenario, tomorrow's threat is assumed to have a substantially better radar and much longer-range missile than today's threat. When the low-stealth fighter (LSF) engages tomorrow's threat, its avionics and AMRAAM have only a modest superiority over tomorrow's threat in beyond-visual-range combat. The JSF gets the first missile launch, but the threat is able to launch a missile in return before the AMRAAM has entered its autonomous homing stage. This tends to draw the JSF

<sup>1</sup>We assumed all three JSF concepts had the AIM-9X and an HMS.

into the much more lethal close-in combat. Because of the reduced signature of the medium-stealth fighter (MSF), the threat aircraft is not able to launch a missile at it until the AMRAAM has entered its autonomous homing stage. This allows the MSF to avoid being drawn into the more lethal close-in combat and achieve an exchange ratio of roughly 6 to 1. With the high-stealth fighter (HSF), the first AMRAAM fired will nearly impact upon the threat before the threat is able to launch a missile in return. Often, the threat is too busy avoiding the JSF's AMRAAM to launch a missile in return at the HSF. This drives the exchange ratio even higher to 9 to 1.

We examined options other than stealth for achieving superiority over the threat and found that the LSF performance could be improved. For example, enhancing the propulsion and warhead on the AMRAAM could reduce the stealth requirements.<sup>2</sup> There are an equal number of options that could increase the stealth requirements. We assumed that all three stealth concepts included an electronic countermeasures (ECM) suite that was effective against monopulse radar missile threats. If the ECM suite on the JSF is not effective against monopulse threats, the JSF may need more stealth to maintain the same level of superiority over the threat as the F-16C enjoys today.

To conclude the air-to-air analysis, if the services want an aircraft with the same margin of superiority in air-to-air combat over tomorrow's threat that the F-16C enjoys over today's threat, they probably need a moderately stealthy aircraft.

## SUMMARY

Figure 4.10 summarizes the results of the stealth study. We again note that these threat environments are not as severe as those postulated for eastern Europe or the Soviet Union during the Cold War. In regional conflict scenarios the defense coverages do not overlap as much and do not cover as much of the theater.

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<sup>2</sup>An analogy is lengthening the JSFs "spear" (longer-range AMRAAM) versus shortening the threat's "spear" (JSF stealth).

RANDMR719-4.10

**Attacking Fixed Targets**

Standoff (nm)	Day of Conflict			
	1	3	7	10+
0	HSF	HSF	MSF	LSF
5	HSF	MSF	MSF	LSF
15	MSF	MSF	LSF	LSF
30	LSF	LSF	LSF	LSF

RF signature required to hold all fixed targets at risk with support from TLAMs, heavy bombers, and 12 SEAD aircraft.

**Attacking an Armored Column**

Standoff (nm)	Defensive System	
	Medium-Range SAM	Long-Range SAM
0	HSF	
5	MSF	HSF
15	MSF	HSF
30	LSF	MSF

RF signature required to attack armored column without being engaged by the defensive systems.

**Air-to-Air Engagements**

	Threat Aircraft	
	Today's Threat	Tomorrow's Threat
Baseline	LSF	MSF
ECM not effective	MSF	HSF
Improved AMRAAM	LSF	LSF

RF signature required to maintain the same level of superiority over the threat as the F-16C has today.

**Figure 4.10—Stealth Summary**

In attacking fixed targets, our analysis suggests that an HSF is needed only on the first day of the war and to overfly targets during the first week of the war. We found that an MSF or even LSF was probably sufficient after the first week of the war. In attacking an armored column, depending upon air defense assumptions, an MSF or even LSF may be sufficient. In the air-to-air analysis, we found that a low- to medium-stealth fighter will maintain the same level of superiority that the F-16C enjoys today.

This analysis was not intended to determine if a derivative of an existing aircraft can meet the JSF need. In conducting our stealth analysis, however, we did not find a circumstance where the LSF was



clearly unsurvivable in the future regional conflicts examined. Our analysis suggests that derivatives of existing designs may be viable and should not be excluded from consideration solely because of survivability concerns.

Finally, we note that the achievement of high levels of stealth is very likely to cause serious design compromises in terms of flexibility and cost. Since the JSF is, essentially, intended to be an inexpensive multirole aircraft, care must be taken to ensure that stealth requirements are not set so severely that other design goals cannot be met. In all three stealth analyses, we found that moderate stealth, coupled with some degree of standoff and advanced countermeasures, is probably sufficient for survivability in regional environments in all but the highest threat situations. Highly stealthy bombers and air superiority fighters are being built to fight and win in just these high-threat situations. First-day survivability in high-threat environments could place too high a cost on an aircraft that may need to replace 65 percent of the force structure.

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**MANEUVERABILITY TRADE-OFFS**

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In this chapter we examine the maneuverability needs of the JSF. The primary reason for requiring a high-turn-rate aircraft is to ensure superior agility for close-in air-to-air combat. Based on previous analyses conducted at RAND, specifically the AIM-9X Cost and Operational Effectiveness Analysis (COEA), we hypothesized that with the advent of high-performance short-range air-to-air missiles (e.g., AIM-9X and ASRAAM) and a helmet mounted sight, the services could save money by backing off on aircraft turn-rate requirements without overly compromising close-in air-to-air combat capability. We examined two scenarios. The first was a strike mission in which the JSFs are equipped primarily with air-to-ground weapons but must defend themselves against several interceptors that have leaked through the escorts. The second mission examined, but not reported on here, was a defensive counter-air mission in which the JSFs are protecting an airfield from enemy strike aircraft. The conclusions were the same for both scenarios.

To “bound the design space,” three levels of JSF turn-rate performance are examined (see Table 5.1). The lowest level of performance was an aircraft design optimized for the strike mission (similar to an A-6). The second level of performance was an aircraft designed for multirole missions similar to a fourth-generation fighter like the F-16. The third level was an aircraft optimized for air-to-air

**Table 5.1**  
**Turn-Rate Performance**

	Sustained "G"	Instantaneous "G"
~ Strike	2 (.9 M/30 kft)	7
~ Fourth generation	3	9
~ Fifth generation	4	9

combat with turn-rate performance of a fifth-generation fighter similar to the F-22.<sup>1</sup>

The avionics and weapons loads were the same for all three aircraft. They were equipped with a radar similar to an electronically steerable APG-68. For defensive systems, they were equipped with a radar warning receiver with the same performance as an ALR-69, plus flares and chaff. We used the Tac Brawler air combat model for this analysis.

Shown in Figure 5.1 is the strike scenario we examined. Four JSFs penetrate enemy air space with air-to-ground ordnance and two AIM-9s at .9 Mach at an altitude of 500 feet. There are two threat interceptors 75 nm away that have leaked through the escorts and are descending to engage the JSFs. The interceptors are receiving ground control intercept (GCI) vectoring on a collision course with the JSFs. The JSFs are not receiving GCI vectoring. As soon as the JSFs detect the interceptors, two JSFs climb to engage the interceptors and two JSFs attempt to avoid the interceptors.

The three threat aircraft used in this analysis are the MiG-23, SU-27, and the MFI (Multirole Fighter/Interceptor). The MiG-23 represents the primary threat when the F-16 was introduced. The SU-27 Flanker represents today's threat, and the MFI represents the primary threat when the JSF is introduced.

Figure 5.2 shows the engagement results. The horizontal axis shows the various aircraft concepts. The vertical axis measures the U.S. air-

<sup>1</sup>This should not be considered an analysis of the F-22 in close-in combat. This analysis does not include F-22 avionics, only F-22-like turn-rate performance. We use F-22 as an example of a fifth-generation fighter.

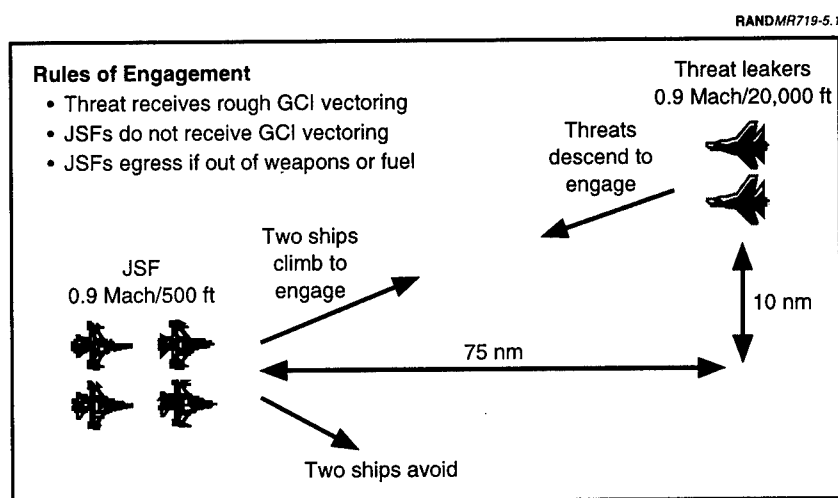


Figure 5.1—Strike Scenario

craft probability of survival in the engagement. As a reference, the left side shows the probability of survival for the F-16A against its initial threat, the MiG-23, and the F-16C against today's threat, the SU-27 Flanker.<sup>2</sup> Illustrated on the right are the three JSF concepts with varying degrees of maneuverability. In this analysis, we can compare the three JSF concepts against its initial threat (MFI), the F-16A against its initial threat (MiG-23), and the F-16C against today's threat.<sup>3</sup> The dark bars represent the probability of survival of the JSF with the AIM-9M and no HMS. The lighter bars show the probability of survival with the AIM-9X and an HMS.

<sup>2</sup>Today's F-16C does not fare well in this analysis because we did not equip it with an HMS or a high-off-boresight missile. Any future F-16 buys probably would include an HMS and the aircraft would fare better in this analysis.

<sup>3</sup>We are assuming that given the similarity between the F-16 and JSF missions, the Air Force would desire the same margin of superiority (in air-to-air combat) for the JSF against its initial air-to-air threat, as the F-16A had against its initial air-to-air threat.

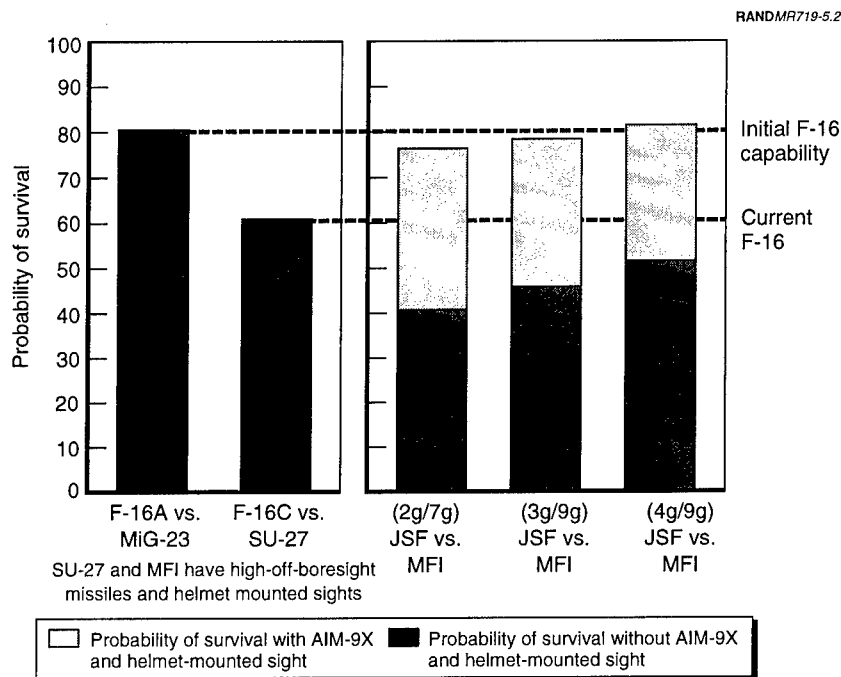


Figure 5.2—Turn-Rate Study Results

The ability of an aircraft to take the first shot often was critical in these engagements.<sup>4</sup> The aircraft that fires first has the first opportunity for a kill and seizes the initiative in the engagement.

The F-16A was almost always able to fire first against the more poorly maneuvering MiG-23 with AA-7 and AA-8 missiles, which led to a probability of survival (for the F-16A) of 80 percent. When today's F-16C faces a Flanker in close-in combat, and the Flanker is equipped with an HMS and highly maneuverable AA-11 missiles, the Flanker almost always gets the first shot, which leads to a F-16C probability of survival of only 60 percent. The MFI, which is assumed to be equipped with an HMS and a highly maneuverable short-range

<sup>4</sup>Air-to-air missiles are fairly lethal in this analysis (~.5 to .6 kills per firing). If the lethality of the air-to-air missiles were lower, the value of firing first would be less.

air-to-air missile, almost always fires first against a JSF (no HMS and an AIM-9M), regardless of the JSF's turn-rate performance, which leads to a probability of survival for the JSF of about 40–50 percent. When the JSF is equipped with an HMS and an AIM-9X, it once again gains the first-shot advantage and raises its probability of survival to 75–80 percent. This analysis suggests that in close-in combat the benefits of high aircraft turn rates are overshadowed by the missile's capability. The JSF may be able to achieve the same level of superiority in close-in combat that the F-16A had over the MiG-23 by having a helmet-mounted sight and an AIM-9X without requiring high levels of turn-rate performance.

The AIM-9X *and* HMS capability are essential to survival in close-in combat when facing a threat equipped with high-off-boresight missiles and HMS. In a close-in fight against a high-off-boresight missile/HMS-equipped opponent, the benefits of high turn rates are overshadowed by the missile's capabilities. In addition, the use of a high-off-boresight missile and HMS may allow an aircraft to defend itself in close-in combat without jettisoning air-to-ground weapons.

We also examined the benefit of high turn rates in avoiding incoming missiles. We found that it was nearly impossible to outmaneuver a modern surface-to-air or air-to-air missile. Modern missiles such as the SA-10 and AA-12 are capable of 40g maneuvers. This maneuverability allows the missile to continue to track even the most maneuverable manned aircraft.

In conclusion, if the requirement for high turn rates is driven by air-to-air close-in combat, the lethality of high-off-boresight short range missiles such as the AIM-9X or ASRAAM and associated targeting aids may permit *some relaxation of high turn-rate performance* in the interests of affordability.

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**COMPROMISES ASSOCIATED WITH  
DESIGN COMMONALITY**

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A crucial consideration in the definition and evaluation of aircraft design requirements is the realism of the proposed requirements and their impact on the weight and cost of the resulting design. Quite simply, it is not enough to poll the war-fighters, run the campaign models, and perform a strategies-to-task analysis that tells us what we “need.” We must also know what is realistic and affordable, and what the optimal trade-offs are between often-conflicting needs.

In the early stages of most previous military aircraft development projects, the services have performed notional design studies to “bound the design space” in terms of realism, affordability, and requirements trade-offs. This same approach was applied at RAND in this study. A reasonable and realistic aircraft configuration design was developed, analyzed, and validated using classical methods and tools. This design was then used to explore requirements and technologies for a next-generation attack fighter, as described below.

To permit reasonable and realistic study of the effect of range and payload requirements on the JSF and the effects of various proposed alternatives for providing triservice capability (i.e., CTOL, CV/CTOL, and STOVL<sup>1</sup>), a notional design concept representing a post-2000 state-of-the-art design was developed by RAND.<sup>2</sup> This aircraft was developed as an analytical tool for trade studies and requirements

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<sup>1</sup>Conventional takeoff and landing, carrier takeoff and landing, and short takeoff and vertical landing.

<sup>2</sup>For a more complete description of this design, see *Design Concepts for the Next Generation Attack Fighter*, by Dan Raymer, RAND, MR-595-AF, 1996.

evaluation, and was created using industry-standard methods and design practice (to the greatest extent possible). We believe that the resulting concept is realistic enough that the results presented below can be considered generically representative of what the aircraft contractors' actual designs would produce, were the same trade studies to be performed with the same assumptions.

This effort began with the establishment of initial design requirements as listed below:

- 550 nm high-medium-medium-high (HMMH) design mission profile (AF baseline, nominal engine)
- 700 nm maximum radius
- Internal carriage of two 1000-lb JDAM, two AIM-120C guns
- 7.33 g load factor at mid-mission fuel weight
- 3.5 g sustained turn rate at .9 Mach and 30,000 ft
- 20 deg/sec at 350 kts, 15,000 ft
- Max speed 1.6 Mach at 30,000 ft
- Accelerate from .8 Mach to 1.2 Mach in 30 seconds at 20,000 ft
- 4000 ft takeoff and landing.

These requirements were developed based on preliminary studies of the aircraft needs as currently understood and comparison with current aircraft. Since the purpose of this design effort was to perform trade studies within the plausible design space, these design requirements were deliberately focused at the center of the design space.

From these requirements a notional design concept was developed and analyzed, shown in Figure 6.1. This basepoint initial concept was developed as a land-based aircraft using Air Force assumptions for analytical purposes, but the design was deliberately created with features that lend themselves to conversion to a carrier-based and a STOVL version. Examples include trailing-link landing gear, twin nose-wheels, and side inlets to permit a lift fan or engine behind the cockpit.



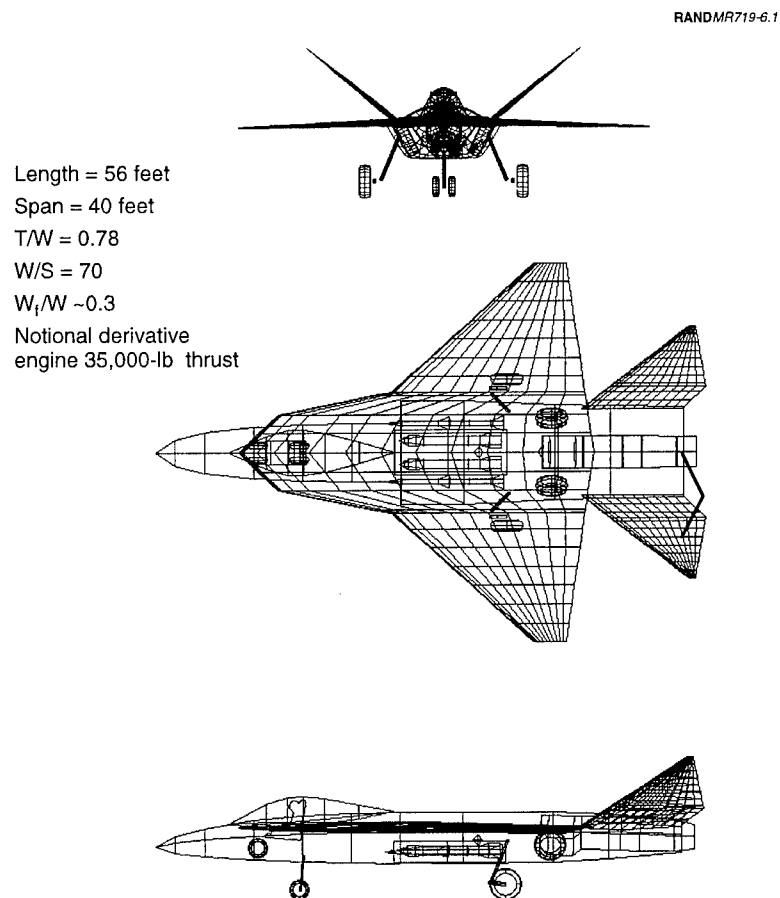


Figure 6.1—Notional Design Concept

The design concept was analyzed using classical means for aerodynamics, weights, and propulsion. Aerodynamic results are summarized in Figure 6.2.

The weight results are summarized in Table 6.1. Propulsion data are based on cycle analysis results provided by Pratt & Whitney Aircraft

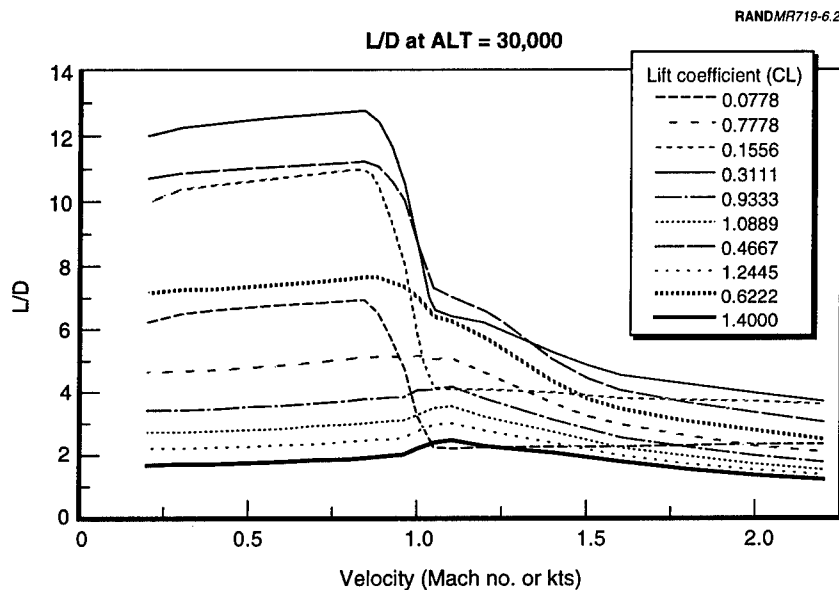


Figure 6.2—Lift-to-Drag Ratio

Engines. All of these results track quite well with results obtained by contractor organizations for similar designs.

Using these results and the mission defined by the design requirements, the concept was then “sized.” In other words, the flight range was calculated for the available weight of fuel estimated for the design, then the total size and weight of the aircraft were adjusted until the range exactly met the requirement of 550-nm radius. This occurs at an aircraft takeoff gross weight of 41,245 lb.

This design concept was used to define a family of configurations developed for a study of options for CTOL, CV/CTOL, and STOVL. The design was used as a point of departure for two multiservice approaches. In one approach, an aircraft would be developed with production line variants for the Air Force and Navy, with the Navy version operating from an aircraft carrier using catapult and arresting gear. As is well known, this adds weight to the design.

**Table 6.1**  
**Summary Weight Data**

Group	Weight (lb)	Group	Weight (lb)
Structures	11267.0	Equipment	4924.7
Wing	4088.5	Flight controls	1020.8
Horiz. tail	0.0	Instruments	128.8
Vert. tail	789.4	Hydraulics	171.7
Fuselage	4748.8	Electrical	706.5
Main landing gear	775.1	Avionics	1945.4
Nose landing gear	318.1	Furnishings	391.7
Engine mounts	62.3	Air conditioning	536.0
Firewall	113.0	Handling gear	23.8
Engine section	48.9	Misc. empty weight	2920.0
Air induction	322.9	Total weight empty	25505.5
Propulsion	6393.8	Useful load	15739.5
Engine(s)	4930.0	Crew	220.0
Tailpipe	0.0	Fuel	11765.5
Engine cooling	273.0	Oil	50.0
Oil cooling	37.8	Cargo	2860.0
Engine controls	21.2	Passengers	0.0
Starter	72.9	Misc. useful load	844.0
Fuel system	1058.9	Design gross weight	41245.0

NOTES: Empty CG = 33.4; loaded—no fuel CG = 32.5; gross wt CG = 33.0; empty weight sizing coefficient (for small changes):  $C = -.335$ .

For this design study, a carrier-suitable CTOL design was found by adding a heavier landing gear, hook, catapult gear, wing fold, and various internal structural beef-ups associated with carrier operation. An Air Force land-based derivative of this was defined by removing catapult gear, reducing the hook and landing gear to land needs, and eliminating the wing fold (saving a portion of the weight penalty).

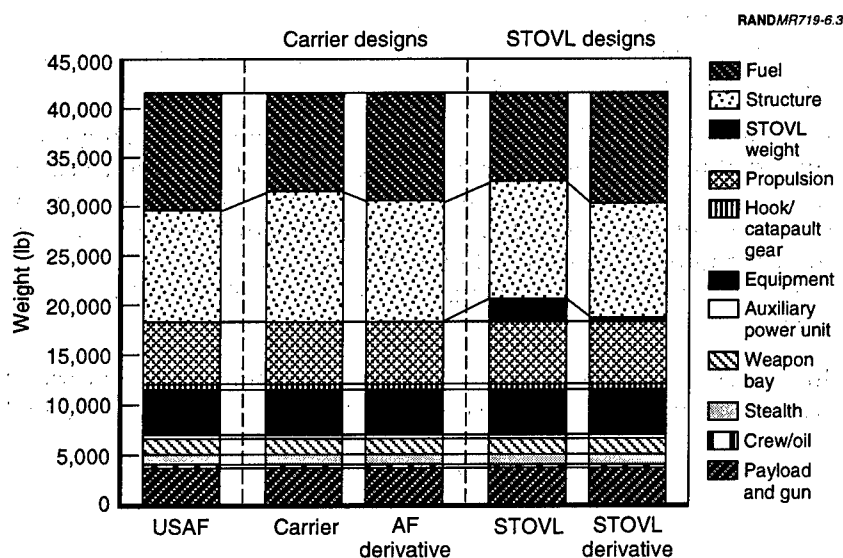
In an alternative two-way modularity approach, a STOVL version of the design was defined along with a land-based CTOL derivative. Carrier operation would be provided through the use of the STOVL gear for both Navy and Marine aircraft. An Air Force version would remove the STOVL gear to save weight.

The STOVL design used the lift-plus-lift-cruise technology, which is one of only two operationally proven STOVL approaches and is simi-

lar in design approach and weight penalty to the remote-fan lift concepts being studied under contract to the Defense Advanced Projects Agency. The fuselage length was stretched three feet to make room for the lift engine. For the CTOL derivative, the lift engine, extra nozzles, and wing fold were removed. It was assumed that the fuselage stretch would be retained, and probably used for fuel, avionics, or growth capacity.

The aircraft empty weight effects of these changes were analyzed at a fixed takeoff gross weight and are shown in Figure 6.3.

The resulting ranges, shown in Table 6.2, were calculated over a HMMH mission similar to the JSF reference mission. Note that the initial CTOL, non-carrier-based base-point has the greatest range because it does not have the empty weight penalties of the CV, STOVL, or derivative designs. Also note the additional penalty of using Navy engine ground rules, which assume a worst-case engine and add an additional 5 percent fuel flow safety factor.



**Figure 6.3**  
Figure 6.3—Aircraft Empty Weight

**Table 6.2**  
**JSF Concept Ranges and Weights for Two-Way Modularity**

Item	USAF	Carrier	AF Deriv	STOVL	STOVL Deriv
Aircraft empty weight (lb) <sup>a</sup>	25,500	27,310	26,500	28,440	26,140
Aircraft radius (nm)	550	350	465	285	500
Takeoff weight (lb) (radius = 550 nm)	41,245	48,350	43,900	51,135	42,820

<sup>a</sup>Holding takeoff weight at 41,245 lb.

We see that, while the Navy gets slightly more range from the CV/CTOL carrier-based approach, the Air Force actually gets slightly more range from a derivative of a STOVL aircraft than from a derivative of a CV/CTOL aircraft (500 nm versus 467 nm).

Resizing these alternative approaches to meet a fixed, 550-nm design mission gives the results shown in Table 6.3. However, one would probably not desire to size the aircraft up much past the 41,245-lb baseline weight because the empty weight grows substantially past 25,000 lb, which has a strong cost impact.

In performing the above analysis, we used traditional fuel ground rules that require that the aircraft structure and performance calculations be made at a mid-mission fuel weight, typically 50 percent or 60 percent of total internal fuel volume. Sizing the primary structure to this requirement, even including the use of advanced composites, makes it very difficult to attain a fuel fraction much over 25 to 30 percent.

In service, though, current aircraft are often flown at an overload weight through the use of external fuel tanks. These increase fuel

**Table 6.3**  
**JSF Concept Ranges with Overload Fuel**  
**(radius in nm)**

USAF	Carrier	AF Deriv	STOVL	STOVL Deriv
995	760	905	695	940

NOTE: Takeoff weight set at 48,120 lb.

weight up to perhaps a 40 percent fuel fraction, with very little increase in empty weight. Since external fuel tanks are undesirable for a stealthy design, a study was made of the penalty and payoff for providing such overload volume inside the aircraft. It was assumed that 1000 gallons of extra fuel volume was provided internally, adding 200 lb of sealing, pumps, and fuel lines, and the resulting ranges were calculated. Ranges calculated with this internal overload fuel volume are shown in Table 6.3.

Ranges are substantially increased, as would be expected. At mid-mission, the aircraft is heavier than it would be without the use of this extra fuel, and so performance and load factor limit are reduced.

The results of the two-way modularity study are summarized in Figure 6.4. Key conclusions are that the CV/CTOL approach offers the Navy a slightly better plane, but the derivative of the STOVL design is better for the Air Force. Furthermore, the two-way modularity of CV/CTOL and Air Force derivative does not provide a means of meeting the Marine Corps need for a new STOVL aircraft.

Another option for multiservice procurement of a next-generation attack fighter is to use a “three-way modularity” approach in which some aircraft are built with STOVL equipment, some are built for catapult and arresting hook operation, and some are built only for conventional land-based operation.

The key problem with this approach is the residual, or “scar” weight penalty associated with design for carrier-based operation. Use of catapult gear on the carrier imposes forward loads of two to three times the aircraft’s weight, and the arrested landing imposes rearward loads of almost double the aircraft’s weight. These loads require extensive redesign and structure strengthening; a keelson structural arrangement often must be used; and many structural members must be thickened.

Such structural overdesign is deeply embedded, affecting virtually every part of the primary structure. When developing a noncarrier derivative for the Air Force, the extra design, test, and manufacturing efforts to remove these overstrength penalties have never to date proven worth the savings.

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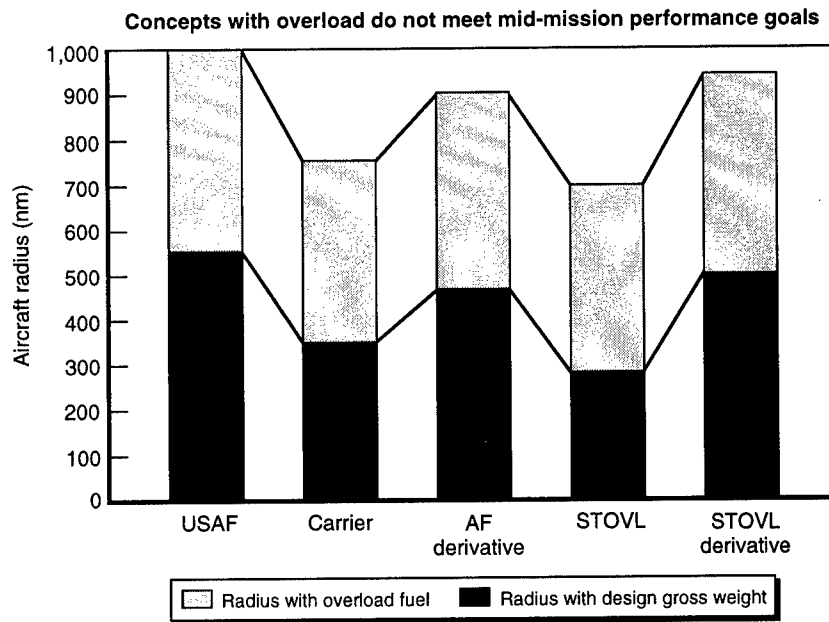


Figure 6.4—Radius Effect of Two-Way Modularity

If this scar weight penalty is added to residual STOVL penalties for all three versions of the aircraft, the combined effect penalizes all of the services' aircraft. To study the magnitude of this effect, a common-core design was evolved from the base-point described above, and three modular versions were developed—CV/CTOL for the Navy, land CTOL for the Air Force, and STOVL for the Marine Corps. The common core includes the residual/nonremovable "scar" penalties for both CV/CTOL and STOVL, as described above. Note that the same wings and tails were used for all three services, to keep as much commonality as possible.

Range and weight results are provided in Table 6.4. Three-way modularity, with less commonality than the two-way modularity approaches outlined above, provides roughly 5 percent less range for the Navy and Air Force than would a traditional CV design plus land-based derivative. Compared to the CV/STOVL approach, the Navy

**Table 6.4**  
**Three-Way Modularity Results**

Item	USAF	Carrier	STOVL	Land
Takeoff weight (lb)				
(radius = 550 nm)	41,245	49,400	54,780	44,950
Empty weight (lb)				
(Takeoff weight = 41,245 lb)	25,505	27,690	29,690	26,880
Radius (nm)	550	320	195	435
Overload radius (nm)				
(Takeoff weight = 48,120 lb)	995	725	600	865

version of the “three-way” modularity design gains about 4 percent in range, but its Air Force derivative has about 8 percent less range compared to a derivative of a STOVL design. Also, there would probably be a higher total program cost because of reduced commonality.

In the broadest sense, this research has confirmed that a single-seat, single engine fighter using a near-term engine and currently available advanced technologies could provide a substantial advantage in range, payload, and signature over current aircraft. A crucial decision must be made early on as to how to handle triservice needs. Options include development of (1) a single, fully-common aircraft, (2) a two-way modularity approach with one aircraft for the Navy and Marine Corps and a highly common derivative for the Air Force, or (3) a less-common “three-way” modularity approach with a STOVL variant for the Marine Corps and a catapult-capable CTOL variant for the Navy.

Table 6.5 summarizes the options studied here for triservice approaches, with aircraft range, at the given takeoff weight, used as a measure of merit. In the first column are the service-optimized designs—what each service could get if it developed a design based on the notional concept described in this report, without penalties associated with compliance with other services’ needs (note that these numbers are pessimistic since no account was taken of the possibility of changing the design requirements—such as range, speed, or payload—for each service).

In the next two columns are the results for the two-way modularity options studied. The Air Force is penalized for the multiservice de-



**Table 6.5**  
**Comparison of Alternatives: Mission Radius**  
**(in nm)**

Service	Service-Optimized Design		Two-Way Modularity (Carrier Based)		Two-Way Modularity (STOVL Based)		Three-Way Modularity (Common Core)	
	Design	Overload	Design	Overload	Design	Overload	Design	Overload
USAF	550	995	465	905	500	940	435	865
USN	395	830	395	830	320	760	365	795
USMC	322	760	No STOVL Option		320	760	225	660

NOTE: "Design" means radius at design takeoff gross weight. "Overload" means radius at maximum overload takeoff gross weight using overload internal fuel.

sign, but to a lesser extent if the Navy uses STOVL. In the third column, the three-way modular approach, with its combined scar weights, shows the worst results for the Air Force and Marine Corps, but a slight improvement for the Navy over using STOVL from carriers. These three-way modularity results could, of course, be improved if it is assumed that modern manufacturing techniques would allow minimizing the scar weight penalties without adding risk to the overall program, but this remains to be proven.

Based on the results of this study, the key desires of all three services can best be met with a highly common two-way modularity approach using STOVL for both the Marine Corps and Navy. By using a ski-jump or by providing a "soft-cat" capability for a slight assist from the catapult, the Navy could operate at the increased takeoff weights needed for maximum range and payload, but without penalizing the basic aircraft in terms of structural weight and wing geometry as would a traditional carrier-suitable capability. The Air Force derivative could then be a highly common production-line variation with the STOVL lift equipment removed, some changes to mission avionics, and virtually everything else the same. Also, the unused lift engine or fan space could be used for a second seat for training aircraft, with no change to primary structure, if that possibility is specified in the initial design process.

While a more-aggressive three-way modularity approach with differing wings, fuselage structure, and other components would undoubtedly offer a bit more range, the penalties associated with a re-

duction in hardware commonality must be considered. These include additional development, production, and support costs deriving from increased design effort, increased testing (both ground and flight), increased program management complexity, increased tooling, lessened learning-curve effect for production and support, a longer logistics pipeline, increased software development and support, and increased costs for later enhancements.

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## CONCLUSIONS

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The Air Force faces a difficult challenge in sustaining its fighter force structure. Its most numerous and versatile fighter, the F-16C/D, will begin to reach the end of its service life in the next 10 to 15 years. If the F-16s have a 6500-hour service life instead of 8000 hours, the F-16s will need to be replaced five years earlier. These aircraft were bought under Cold War budgets at a rate of over 150 aircraft per year. For the Air Force to sustain a 16-20 fighter wing force, it will need to procure aircraft at a rate of over 120 aircraft per year.

Future budgets will make replacing the F-16 with a new aircraft (at rates of 120 aircraft per year) a difficult challenge. If the federal budget is balanced, increasing the pressure on discretionary spending and reducing the DoD and Air Force budgets, the Air Force will probably not be able to afford to buy the kinds of airplanes it wants in the quantities it desires. Modernizing to a 20 FWE force of F-22s and JSFs will require supplementing that traditional share of the budget for fighter acquisition by making trade-offs with other systems and accounts, perhaps changing the high/low mix of aircraft and buying an F-16 replacement with a lower cost than currently contemplated for the JSF.

Against a backdrop of declining or flat DoD budgets, intergenerational cost increases of aircraft are offsetting savings that might otherwise accrue from buying fewer aircraft for smaller force structures. Procurement accounts have declined significantly while infrastructure spending is still close to Cold War averages. Fighter aircraft face strong competition for acquisition funding from other programs.

Based on historic priorities for projected DoD budgets, if the Air Force wants to maintain 20 fighter wings with four wings of F-22s, then it can only afford \$26 million per JSF aircraft. If the cost of the JSF is not constrained to \$26 million, then the Air Force will have to either increase the budget share for fighters by reducing budgets elsewhere or reduce its force structure goals. Even with rigorous cost controls, challenges lie ahead in introducing a JSF without creating an unaffordable budget bow wave as the Air Force acquires several new systems at the same time after the turn of the century.

Shown in Figure 7.1 are three problems the Air Force is facing in modernizing the fighter force structure and several options the Air Force has for dealing with these problems. The three problems across the top are short-term attrition of the F-16C fleet (described in Chapter One), the four years of procurement overlap between the F-22 and JSF, which causes a budget bow wave, and JSF affordability (the Air Force can only afford a \$26 million flyaway cost per aircraft, which is roughly the cost of an F-16).

None of the options for dealing with these three problems is painless. The Air Force could extend the life of 370 F-16s by 4000 hours through a SLEP. This would eliminate the short-term attrition problem and, by delaying the need for the JSF by four years, would eliminate the F-22 and JSF procurement overlap—but could cost as much as \$3.7 billion. A more attractive option may be to procure new current-generation aircraft. Procuring 180 new F-16Cs or F-15Es would cost between \$5.5 and \$6.2 billion but would provide the Air Force with a more modern force structure. The Air Force could “buy its way out of this problem” by spending \$5 billion a year on fighter modernization, but programs outside of fighter modernization would have to be cut. If the Air Force did not retire the F-15A/Bs early, it could extend the date for JSF introduction by 1 year and eliminate the short-term attrition problem. If the Air Force were to reduce the flight hours on the F-16Cs by 40 percent it could delay the JSF by four years, but this would have severe effects on training and readiness. Cutting the length of the F-22 buy in half would eliminate the procurement overlap but would have little effect on the short-term attrition problem and JSF affordability. Finally, if the Quadrennial Defense Review (QDR) were to reduce the force structure to 18 fighter wings, the short-term attrition problem and pro-

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Option	Problem			
	Short-term attrition	Procurement overlap (F-22, JSF)	JSF affordability	Notes
Baseline	Aircraft shortfall in 2001	4 years	\$26M	
Extend life of current fighters (F-16)	Eliminates	Eliminates	No change	Cost ~\$3.7B
Buy additional current-generation fighters	Eliminates	Eliminates	Frees up \$2M per aircraft	Cost \$5.5–\$6.2B
Spend more on fighter modernization (\$5B/yr)	No change	No change	Frees up \$10M per aircraft	Other programs would have to be cut
Do not retire F-15 A/Bs early	Eliminates	One less year of overlap	Frees up \$2M per aircraft	Changes force composition
Fly current fighters less (F-16)	No change	Eliminates	No change	Saves \$5B but reduces readiness
Buy fewer F-22s	No change	Eliminates	Frees up \$4M per aircraft	Yearly rate remains the same; length of buy cut in half
QDR reduces force structure to 18 FW (without a budget cut)	Eliminates	Eliminates	Frees up \$6M per aircraft	2 FWs are used as attrition reserve

**Figure 7.1—Options for Dealing with Fighter Modernization Problems**

curement overlap would be resolved. The point of Figure 7.1 is to show that no one option solves all three problems.

*The Air Force faces formidable challenges in keeping the JSF affordable. If cost per aircraft is not constrained (to \$26–\$28 million), the Air Force will have to either increase the budget share for fighters by reducing budgets elsewhere or reduce the fighter force structure. In any case, introducing a JSF could create an unaffordable budget spike*

*unless the Air Force extends the life of (or procures more) current-generation aircraft.*

The new environment, featuring regional threats rather than a superpower competition, may provide some relief from the stringent requirements that drove up costs during the Cold War. A total force perspective is essential for setting affordable design parameters. Other assets, such as standoff weapons, advanced air-to-air missiles, and heavy bombers, can complement the JSF to permit some relaxation of its design requirements. Nevertheless, the Joint Strike Fighter will be the most versatile multirole fighter ever built, and making it affordable will be a serious challenge. Affordability will continue to be an important ingredient in the design trade-off process.

The requirement for stealth is not as stringent as it was during the Cold War era. An aircraft with moderate stealth, some standoff capability, and advanced countermeasures should be adequate in future regional conflicts. Our analysis suggests that a high degree of stealth is required only during the first day of the war and to overfly targets during the first week of the war. Relying on TLAMs launched from carrier battle groups, the heavy bomber force, standoff weapons, and an effective SEAD campaign may permit the relaxation of stealth requirements for the sake of affordability. Derivatives of existing aircraft may be viable and should not be excluded from consideration solely on the ground of survivability.

An aircraft with a radius of 650 nm (845 nm with a 30 percent increase for mission planning and dog-legs) is probably sufficient for the JSF. An aircraft with a 650 nm radius can reach 70 percent of the targets (with heavy bombers and TLAMs attacking the other 30 percent of the targets) for all basing options with some in-flight refueling support.

The requirement for high turn rates is driven mostly by air-to-air close-in combat. Our analysis suggests the lethality of high-off-boresight short-range missiles such as the AIM-9X or ASRAAM and associated targeting aids may permit some relaxation of high turn-rate performance in the interests of affordability.

A crucial decision must be made early on as to how to handle tri-service needs. Options include development of a single, fully

common aircraft, or a two-way modularity approach with one aircraft for the Navy and Marine Corps and a highly common derivative for the Air Force, or a less-common three-way modularity approach with a STOVL variant for the Marine Corps and a catapult-capable CTOL variant for the Navy.

Our analysis suggests the key desires of all three services can best be met with a highly common two-way modularity approach using STOVL for both the Marine Corps and Navy. By using a ski-jump or by providing a "soft-cat" capability for a slight assist from the catapult, the Navy could operate at the increased takeoff weights needed for maximum range and payload, but without penalizing the basic aircraft in terms of structural weight and wing geometry as would a traditional carrier-suitable capability. The Air Force derivative could then be a highly common production-line variation with the STOVL lift equipment removed, some changes to mission avionics, and virtually everything else the same.

While a more-aggressive three-way modularity approach with differing wings, fuselage structure, and other components would undoubtedly offer a bit more range, the penalties associated with a reduction in hardware commonality must be considered. These include additional development, production, and support costs deriving from increased design effort, increased testing (both ground and flight), increased program management complexity, increased tooling, a lessened learning-curve effect for production and support, an increased logistics pipeline, increased software development and support, and increased costs for later enhancements.